VOLUME XXV NUMBER 4

THE

JOURNAL OF GEOLOGY

MAY-JUNE 1917

LABIDOSAURUS[1] COPE, A LOWER PERMIAN COTYLOSAUR REPTILE FROM TEXAS

SAMUEL W. WILLISTON
University of Chicago

Although remains of the genus *Labidosaurus* are not rare in the upper Clear Fork beds of Texas, it has only been lately that fairly complete skeletons have been secured. During the past season Mr. Paul C. Miller was fortunate in finding, not far from the paleontologically famous Craddock Ranch, near Seymour, Texas, some half-dozen specimens, associated in a spot but a few square yards in area—specimens which furnish nearly every detail of the skeletal structure, excepting, as usual, the length of the tail. These specimens come from a horizon that I have several times mentioned, that from which the connected skeletons of *Seymouria* and *Trimerorhachis*, previously described, were obtained. Like those, these skeletons were inclosed in hard clay nodules of a mottled red and white color. The bones are rather soft and white in color, while the matrix is very hard, making their preparation difficult.

[1] *Labidosaurus* Cope, *Proc. Amer. Phil. Soc.*, 1896, p. 185; Case, *Zoöl. Bull.*, II (1899), 231 (*Pariotichus*); *Revision of the Colylosauria* (1911), 45, 101; *Permocarboniferous Beds of North America, and Their Vertebrate Fauna*, p. 137, 1915; Broili, *Paleontographica*, XI (1905), 51; Williston, *Jour. Geol.*, XVI (1908), 359; *ibid.*, XXII (1914), 65; *ibid.*, XXII (1914), 414; *Contributions from Walker Museum*, I, No. 8 (1914), 157; *ibid.*, No. 9 (1916), 221; Branson, *Jour. Geol.*, XIX (1911), 136; v. Huene, *Bull. Amer. Mus. Nat. Hist.*, XXXII (1913), 351.

The most important of these specimens (No. 174 Fig. 1), that upon which the restoration (Fig. 8) chiefly is based, includes the right half of the skull, the connected series of vertebrae and ribs to the base of the tail, the pectoral girdle, the humerus, the radius, the ulna, a single metacarpal, the pelvis, seen from below, and the right hind leg complete, except the phalanges of the fourth and fifth toes. Another specimen (No. 177) comprises the skull, a

FIG. 1.—*Labidosaurus*. Specimen No. 174, as prepared. One-fourth natural size.

complete series of closely articulated vertebrae and ribs to the second sacral, the clavicular girdle in place, a part visible of the left scapula, the left front leg, with the exception of most of the phalanges, a femur, and part of the pelvis. This specimen has been laid bare on the ventral side. A third specimen (No. 176) has the skull with its upper part largely destroyed, the series of vertebrae and ribs nearly to the sacrum, the pectoral girdle, both humeri, one forearm, and part of the hand. The fourth specimen (No. 178) comprises a complete skull, the connected vertebrae to about the middle of the back, and the connected pectoral girdle. The other specimens are more fragmentary and have not yet been prepared.

In addition to these specimens preserved in their matrix, there are eight other more or less complete skulls, as many more incomplete, and numerous series of vertebrae, girdles, and limb bones—altogether about thirty specimens. The material, it will be seen, is ample to determine the skeletal structure.

In size, these specimens vary not a little. About half of them are of nearly uniform size, the skull measuring seven inches along the median line; these clearly all belong to the type species *L. hamatus* Cope. Four other skulls, including the one originally described by Case and myself as *Labidosaurus* (*Pariotichus*) *incisivus* (No. 634) and Nos. 174 and 178 measure five inches along the midline. All of these, unless it be No. 634, come from the upper Clear Fork horizon. Two other skulls, and parts of others, including the maxillae in which the additional maxillary teeth were observed, are of smaller size, measuring only four inches. Two of these (180 and 183) come from a much lower horizon, that which has yielded most, if not all, the known specimens of *Pantylus*. They have but a single row of teeth in the mandibles, and have the long premaxillary teeth, and cannot be placed in the genus *Captorhinus*, though they differ materially from the large skulls in having the face less compressed. Probably they will eventually find a place in another yet unnamed genus. The most important of these is a very perfect specimen (No. 183) herewith figured (Fig. 2). In each orbit there is preserved a part of a sclerotic ring, the earliest appearance, I believe, of such ossifications in a reptile. The separate plates (Fig. 3) are narrow, with a flattened, thumblike projection on each extending over the adjoining plate near its inner end; otherwise they are not imbricated. In specimen No. 174 fragments of similar plates are preserved in the orbit. Doubtless all the members of this group had similar ossifications of the sclera, and it is not at all improbable that most Paleozoic reptiles possessed them.

Skull.—Nearly every detail of the skull of *Labidosaurus* is known with assurance, owing to the combined researches of Cope, Broili, Case, and myself. In the first figure of the skull given by me, the quadratojugal was given as a distinct bone, and also a division of the squamosal into two bones. In my second figure the quadratojugal was omitted as doubtful, as was also the supratemporal. I

thought that I found in two specimens a suture separating the posterior part of the squamosal, and recognized it as the "epiotic," following Cope. A skull acquired very soon thereafter showed clearly that there was no such suture, and that the ascription of a tabular was an error, as recorded by Branson (*op. cit.*). The sutures given in the present figures have been corroborated in at least a dozen skulls, and there can no longer be any doubt about

FIG. 2.—*Labidosaurus*(?). Skull, from the side. Three-fourths natural size. No. 183.

them. The figure given by v. Huene (*op. cit.*), I regret to say, has a number of inaccuracies. There is a distinct quadrotojugal, a bone found in nearly all the American Permocarboniferous reptiles; there is no supratemporal, absent also in *Procolophon* and *Captorhinus;* and no tabular, present in all other cotylosaurs, and in many theromorphs. Of the structure of the under side of the skull I have no corrections to make of my earlier figures. In none of the large specimens is there a trace of the parasphenoid; it is certainly absent in some; in two of the smaller skulls it is present though small. Perhaps its absence is a generic or a specific character. Nor have I any changes to make in my figures of the

occipital region. The paroccipital exists as a distinct bone. The proötic, epipterygoid, and the relations of the quadrate are as I have described and figured them. The small bones above the brain case, which I doubtfully called the "alisphenoids," in the doubt now existing as to the presence of the mammalian alisphenoid in the reptiles may be called the "postoptics," the name first proposed for them by Cope. Nor have I any emendations to make of the structure of the mandible as figured by me.

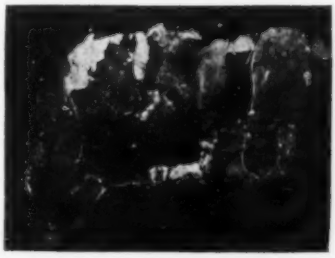


FIG. 3.—*Labidosaurus*. Sclerotic plates. Enlarged.

Whether all the forms have additional teeth on the inner side of the maxillae posteriorly I cannot say since in most specimens the mandibles are tightly closed, precluding an examination of this region. Two smaller maxillae, as recorded by Branson, possess them. The premaxilla has, in most specimens, three teeth, of which the first is the largest, and the third small. Case has based a species, *L. broilii*, on the presence of two elongated premaxillary teeth, but I think that the character is variable. The number of teeth in the maxilla also is variable. In the earlier specimens I could find not more than seventeen or eighteen. In that herewith figured (No. 174) there are twenty-four, the posterior ones quite small. Whether this difference is a specific or an individual character I am not prepared to say. I am unwilling to give specific names until I am assured that I know specific characters, and such we do not know well in any genus from the American Permian—in general I am skeptical of the "species" of all fossil reptiles.

Nearly every skull of *Labidosaurus* hitherto found was fossilized in a horizontal position and it has been exceedingly difficult to determine the amount of depression they had suffered. Among the numerous skulls now at my command there are two only which have not thus been distorted. One, an unusually large skull measuring eight inches in length, shows very little if any distortion. The other, that herewith figured (Fig. 1), had been evenly split along the

median line and the right half has been preserved in articulation with the vertebrae lying upon its side. In this specimen, the slight distortion is in the other direction; its height posteriorly is a little too great. From a study of all these specimens, however, one can determine almost exactly the elevation of the posterior part of the skull, about as I have figured it in the restoration. Whence it follows that in all the figures hitherto given, including my own, the skull is shown too much flattened posteriorly, and the orbits too

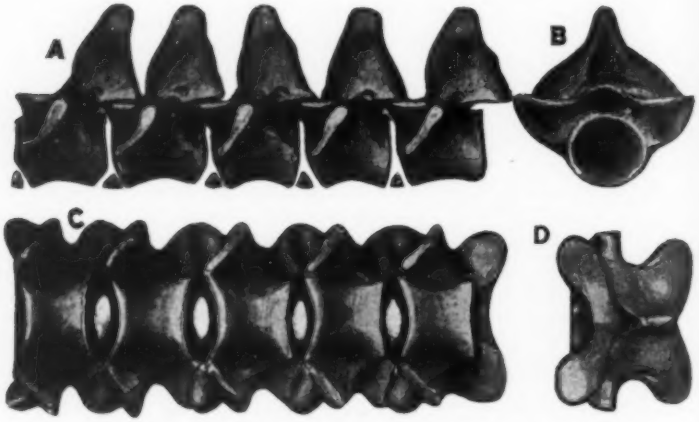


FIG. 4.—*Labidosaurus*. Anterior dorsal vertebrae. *A*, from the side; *B*, from in front; *C*, from below; *D*, from above. Natural size.

ovate in form when seen from the side. In reality the orbits seen from the side are almost circular in outline.

Vertebrae.—The peculiar structure of the vertebrae, which *Labidosaurus* shares for the most part with *Captorhinus*, has been described sufficiently well by Case, and will be seen from the accompanying figure (Fig. 4). Vertebrae of this type are known exclusively from the Texas deposits, with one exception, a specimen of a large form found by Professor Case in the El Cobre Cañon. I believe that when the skull of this genus is discovered it will prove to be of the *Labidosaurus* type. I may add that the horizon of this specimen is rather high up in the Cobre deposits.

The atlas cannot be made out in any of the connected specimens. Doubtless there is also a proatlas. The axis scarcely differs from the following vertebrae. There are twenty-five presacral vertebrae, definitely shown in specimen No. 177. This is the number found by Case in *Captorhinus*, and one less than the number in *Limnoscelis*, a genus which has not a few points of resemblance to *Labidosaurus*. It is two more than is possessed by *Seymouria*, and three or four more than in *Diadectes*. In *Pantylus* the number is unknown.

The postaxial, presacral vertebrae are scarcely distinguishable from each other, except the five posterior ones, which have no processes for rib articulation. The spines anteriorly are a little more slender, giving greater freedom of vertical movement. The transverse processes anteriorly are a little longer, standing out beyond the margin of the zygapophyses; they are also a little stouter here, extending down farther on the sides of the centrum. The intercentra anteriorly are small, not nearly filling out the space between the margins of the centra. There are two sacral vertebrae; the first bears a stout rib, with a broad, vertical face, as long as the centrum, for articulation with the ilium; the second has a much smaller rib, only touching the ilium behind and below the first rib. The caudal vertebrae, so far as known, are narrower than the presacral, and have more slender processes. Their ribs are co-ossified with the centra, unlike those of *Seymouria*.

The first and second ribs are slender; the third is broader and much longer. The fourth, as in *Captorhinus*, is remarkable (Fig. 1) and would hardly be recognized as a rib if found isolated. Its length is less than three times the width of the distal end. It is narrowed in the middle and much expanded at its extremities. Like the early ribs of *Seymouria*, *Diadectes*, and *Limnoscelis*, its function was the support of the scapula.

Pectoral girdle (Figs. 5, 6).—In five different specimens, the pectoral girdle, more or less complete, is found in position with the skull and but slightly dislocated from its association with the vertebral column. In each case the front end of the interclavicle with its articulated clavicles lies between the angles of the jaws and immediately under the occipital condyle—precisely its posi-

tion in the temnospondylous amphibians and in *Diplocaulus*. There was literally no neck in the cotylosaurs. In three of these specimens the shaft of the clavicles is turned dorsad at a right angle to the lower, horizontal, and expanded part; in two or three others the angle is slightly greater. In one specimen, that shown in Fig. 1, lying in immediate connection with the upper end of the

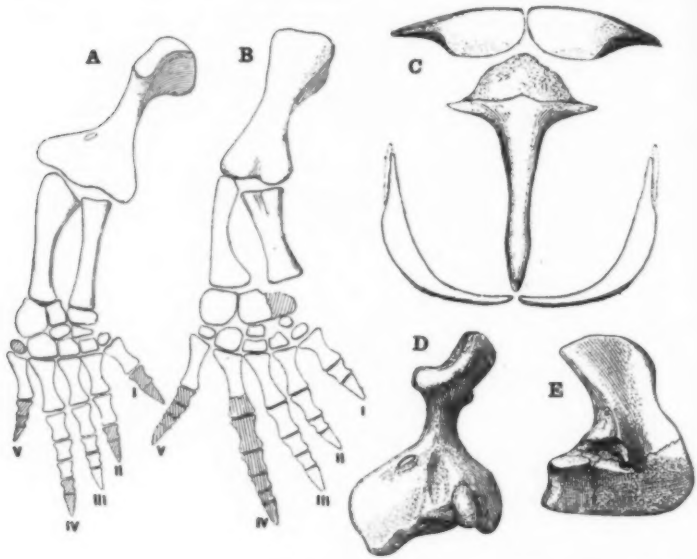


FIG. 5.—*Labidosaurus*. *A*, front leg; *B*, hind leg; *C*, clavicular girdle clavicles from below, interclavicle from below, clavicles from in front; *D*, humerus ventral face; *E*, scapula, outer face (No. 634). All figures about one-half natural size.

clavicle, there is a very slender bone about 20 mm. in length; a similar bone is also found in specimen No. 178 with quite the same relations. There would seem to be little doubt that it is a vestigial cleithrum. In *Limnoscelis* the cleithrum is very small, though much larger in *Diadectes*. None has been observed in *Seymouria*, but I am inclined to believe that all the American cotylosaurs possessed the element, though in some cases it was vestigial. The scapula figured (Fig. 5, *E*), is quite complete, but is lying on its

side and has suffered a lateral compression. In specimen No. 178 (Fig. 6) the scapulae lie almost perfectly in position with the clavicular girdle, or at least that of the left side. The blade may have been pressed outwardly a little, but the angle between it and the horizontal coracoids is nearly rectangular. As a whole, the scapula is rather broad and short, as in *Limnoscelis*, a little narrower in the larger specimen. The sutures separating the coracoids and the scapula have been corroborated in several specimens.

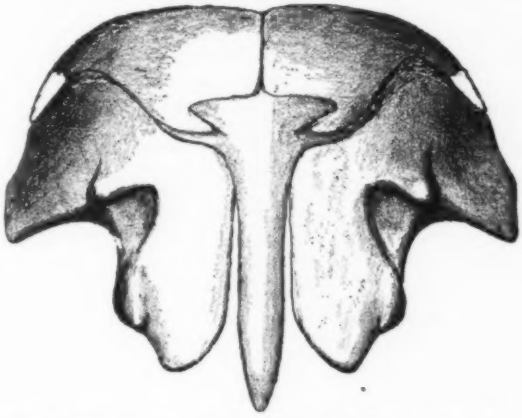


FIG. 6.—*Labidosaurus*. No. 178. Pectoral girdle, from below. One-half natural size.

Forelegs.—The humeri of the different specimens vary appreciably in shape, but I do not know the value of the differences. They have a greatly expanded distal end, as would be called for by the large and stout hand. The radius and ulna are shown connected in three specimens. They are somewhat more slender than the posterior epipodials, and are much shorter than the humerus.

The carpus was correctly figured by me in my earliest paper; unfortunately some of the bones were incorrectly identified: it is the fifth and not the first digit which was missing. There are definitely four phalanges in the third finger, and there can be little, if any, doubt that the formula was the primitive one of 2, 3, 4, 5, 3. The fifth carpale I have not recognized, but it doubtless was ossified.

Pelvis.—Of the pelvis the ilium is not visible in its entirety in any specimen. In the restoration I have borrowed from Broili's figure the outline of the upper part articulating with the sacral ribs. The flat, platelike pubes and ischia are firmly united in the middle, with no opening except the usual obturator foramen; they are proportionally long.

Hind legs.—The femur has been well figured by Case. It is rather short and stout, much stouter than in *Captorhinus*. The tibia is unusually stout, and the fibula is much curved; both bones are much shorter than the femur. My original figure of the tarsus was erroneous in several particulars, as was suggested by Jaekel. Most of the tarsal bones have been correctly figured by Case. In one specimen (No. 174) I find what I believe to be evidence of two centralia, as in *Ophiacodon*, though Case figures but one. The phalangeal formula was doubtless 2, 3, 4, 5, 4. The first three digits are shown in the figure (Fig. 1). The first digit of both the hand and the foot is relatively large, and its metapodial was capable of but little divarication from the others. The fifth metapodial was but little shorter than the fourth.

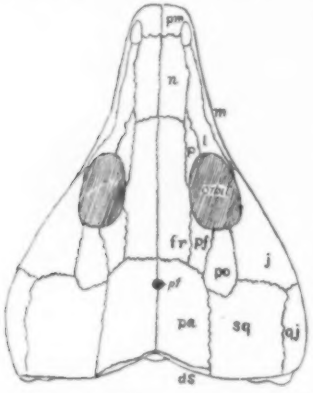


FIG. 7.—*Labidosaurus*. Outline of skull, from above: *pm*, premaxilla; *n*, nasal; *m*, maxilla; *l*, lacrimal; *p*, prefrontal; *fr*, frontal; *pf*, postfrontal; *po*, postorbital; *j*, jugal; *pa*, parietal; *sq*, squamosal; *ds*, dermosupraoccipital; *pf*, parietal foramen. (Engraving from *Water Reptiles*, p. 22, Fig. 6.)

Parenthetically I may add that I do not at all agree with Goodrich[1] in imputing to the form and position of the fifth toe so much importance in the classification and phylogeny of the reptiles. The divarication and hook shape of the fifth metatarsal have been due, I believe, to modifications of the tarsus and doubtless have arisen homoplastically in various lines of descent. In all primitive reptiles there was a fifth tarsale. As has been amply proved, I

[1] *Proc. Royal Soc.*, LXXXIX (1916), 261.

think, the bone has absolutely disappeared in all modern amniotes, leaving a space that was soon occupied by the proximal end of the fifth metatarsal, which came to articulate directly with the large fourth tarsale. In many Permian reptiles a divarication and proximal elongation of the fifth metatarsal had begun. This change in the articulation, it seems to me, will easily account for the change in the form of the fifth metatarsal in crawling plantigrade reptiles. In the rectigrade, and more ambulatory reptiles, on the other hand, with less functional use of the fifth toe, the metatarsal retained more of its primitive shape and position parallel with the fourth, especially in the forms ancestral to the mammals.

The chief fallacy in Goodrich's arguments lies in deriving the stegocrotaphous chelonian skull from a single- or double-arched ancestor because of the shape of the fifth metatarsal. It is now conceded that the turtles must have had a direct ancestry from the cotylosaurian type of reptile; if so the hook-shaped metatarsal must have been an independent acquirement.

The hands and feet of *Labidosaurus* (Fig. 5) are relatively large and powerful, the foot nearly as long as the leg, the hand as the arm. The first digit of each is relatively large and but little divaricated in life; its

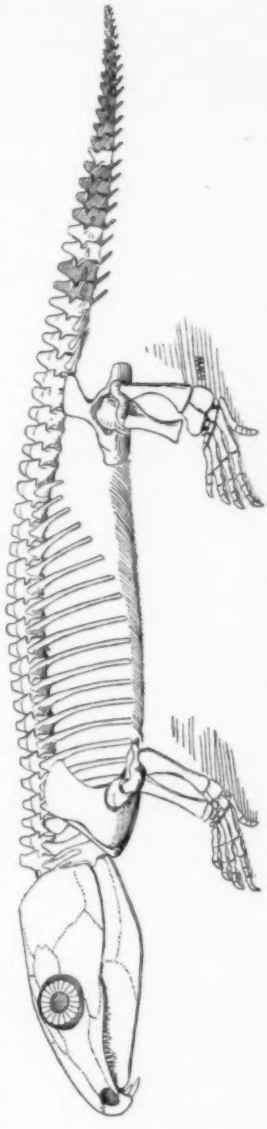


FIG. 8.—*Labidosaurus*. Skeleton. About one-fourth natural size

metapodial is but little smaller than the second. The metapodials are all stout, but the digits are short, tapering rapidly. The ungual phalanges are more pointed than in either *Limnoscelis* or *Diadectes;* the fifth tarsale, as usual, is small.

Very slender ventral ribs, for the first time recognized in this genus among the cotylosaurs, are present in numerous specimens. So far as they are preserved, they do not seem to differ from those of *Ophiacodon* or *Varanops*, for instance. It is pretty certain that they are absent in the diadectids and *Limnoscelis*. Why some genera in each order of reptiles should have retained these bones, while others lost them, I am not prepared to hazard a guess. Possibly they have something to do with water habits.

FIG. 9.—*Labidosaurus*. Life restoration, about one-eighth natural size

Restoration (Figs. 8 and 9).—The only attempt that has hitherto been made at the restoration of the skeleton of *Labidosaurus* is that of Broili, which was quite acceptable, considering our little knowledge of the genus and its allies at the time he made it. That he placed the front legs so far back as he did, is not surprising; almost anyone would have done likewise at the time; and in the curvature of the vertebral column he was unduly influenced by the erroneous early restorations of *Pareiasaurus*, at that time supposed to be a near relative. I may only remark here that the present restoration, based as it is upon so much material, has scarcely anything conjectural about it, or anything that has not been corroborated by several specimens. As usual, the length of the tail is still in doubt. I have assumed that it was about as long as in the allied captorhinids, of which we know the tail more definitely.

Habits.—Granted a fairly complete knowledge of the osseous structure of such early reptiles, there must remain more or less

conjecture as to how and where the creatures lived. The two striking characters seen in the skeleton are the elongated, hooklike incisor teeth and the very powerful feet. Were they correlated? I believe that they were. There is no evidence that the powerful feet were developed for use in swimming, though doubtless the creatures swam well. Nor is there any evidence that the creatures used them for digging holes in which to crawl, for the very good reason that the front legs were altogether too short; they could not have scratched their own noses, much less dig holes for the body to enter. Why not then assume that the feet were developed for digging for food? The epipodials are relatively short, a character constantly found in animals using their legs for propulsion in the water. But why not the same shortening to give greater immediate power in digging? I believe, then, that *Labidosaurus* lived about the lowlands, on the borders of the seas or lakes, and found its livelihood in extricating worms and larvae from the rocks or soil, for which the long, hooklike front teeth were admirably fitted. The posterior teeth in *Labidosaurus* were not strictly carnivorous; they were better adapted for cutting than for tearing or seizing. They are flattened, with an obtusely pointed apex; and the palatine teeth were very small, except those of the "transpalatine" part of the pterygoids. The motion of the head upon the shoulders was limited laterally, rather free vertically. The trunk was not very flexible. The spines were short, but the great development of the arches of the vertebrae furnished ample place for the attachment of muscles controlling the head. Finally, in motion the animal must have been slow and sluggish.

In some respects *Labidosaurus* is the most specialized of all the American cotylosaurs, especially in the loss of the supratemporal and tabular bones, rarely absent in other cotylosaurs; and in the reduction of the dermosupraoccipitals, and their restriction to the occipital surface of the skull. The genus could not have been ancestral to any known later cotylosaurs, though possibly the Captorhinidae may have been allied to the ancestral stock of the Procolophonia of the Trias.

NOTES ON THE 1916 ERUPTION OF MAUNA LOA

HARRY O. WOOD
Hawaiian Volcano Observatory

The writer's observations and comments on this eruption divide naturally into four parts:

I. Distant observation and photographic record of the outbursts of fumes on May 19, and of the beginning of flow on May 21–22, 1916.

II. Observation at the front of the Honomalino branch of flow on May 23.

III. A hurried reconnaissance of the Kahuku branch of flow, and of the flow-source region, on May 30–31.

IV. A thorough examination and photographic record of conditions throughout the region of the source of flow, made in the company of Dr. A. L. Day, in the six days, June 28—July 3, 1916.

Treatment under these headings makes for a somewhat extended and rambling account; but it has been found very difficult to present the complicated sequence of observations, which in some respects are unrelated, in any more succinct way.

I[1]

The beginnings of this eruption were noticed first in the early morning hours of May 19, 1916. No immediate premonitory symptoms were recognized previously. The earliest observations which have come to notice were made by Captain D. F. Nicholson, of the steamship "Hamakua," and by Mrs. R. A. McWayne, of Papa.

At about 3:45 in the morning, while sitting on the bridge as the "Hamakua" was steaming around South Point, Captain Nicholson experienced an earthquake. The sea was smooth and

[1] Much of the matter in Part I was published at once in the *Weekly Bulletin* of the Hawaiian Volcano Observatory, IV, No. 5, pp. 34–37; but this report was necessarily fragmentary, and partly erroneous, so it is restated here.

the weather calm and cloudless. Suddenly the ship trembled from stem to stern, as though it had grounded on a beach, and loose things in the ship's galley were disturbed; also the smooth sea surface suddenly became agitated violently by the commingling of several different systems of waves, an action which kept it in a state of turmoil for about a minute. (No shock so strong as this one was recognizably registered in the Whitney Laboratory of Seismology at Kilauea.)

A little later, at about 4:15 A.M., Captain Nicholson heard a sound lasting for about three seconds, which he likened to a volley of musketry, and he then saw what he described as a spiral column of fumes rising from a point high up on the south flank of the mountain. From her residence above the road near Papa, Mrs. McWayne in the early morning hours saw a bright glow high up the mountain.

During the morning and forenoon hours of May 19 a swarm of local earthquakes was registered at the Whitney Laboratory. All these were extremely feeble shocks, even when considered from the seismographic point of view. The earliest of them was recorded a little before three in the morning. Beginning in the late forenoon a lull followed, less than twenty-four hours in duration.

Throughout the evening and night of May 18, and the morning and forenoon of May 19, the weather was brilliantly clear. Looking westward from the Hawaiian Volcano Observatory, situated on the northeast margin of the crater of Kilauea, one could see nearly the whole profile of Mauna Loa outlined sharply against the sky. From late evening until dawn there was brilliant moonlight. Until midnight, and at 6:15 A.M., no signs of eruption were seen from the vicinity of the observatory. However, at about 6:15 A.M. the beginning of a fresh outburst of fumes, high on the mountain slope, was seen by Captain Nicholson, whose ship had then come to anchor at Honuapo.

At about 7 A.M., perhaps a little before, a definite outbreak and uprush of fumes became visible at Kilauea. At first a group of cloud-forms appeared high up on the south flank of Loa, rising from behind the mountain profile at a distance of at least twenty-five miles, as viewed from near the observatory. Here these were

first seen by Joseph Moniz. Though their appearance and development exhibited peculiarities, Moniz at first thought them to be ordinary cumulus clouds, such as frequently rise from behind the mountain. Yet they held his attention. After about ten minutes, since they continued to rise straight upward at the same place, he pointed them out to others; but still there was doubt as to their character, and he allowed more than a half-hour to pass by before he called the attention of the writer to them, at about 7:35 A.M., having grown surer that they were columns of fumes.

When first seen by the writer there were two chief standing columns in which fumes were swirling rapidly straight upward and merging in a double cumulus crown. The column higher up the slope was somewhat larger and taller than that lower down; and these were then separated by a clear interval whose width was about the same as the diameter of the larger column—about 1,000 feet. As soon as possible the writer began making a series of photographic records of this action, illustrating its development throughout the rest of its duration.[1] Five of these are shown here, Plate II, *a*, *b*, *c*, *d*; Plate III, *a*. The life of this outbreak was short.

The higher fume column then rose above the mountain profile probably from 11,000 to 12,000 feet, and the lower from 8,000 to 10,000 feet. Very quickly other subordinate columns appeared, first at both sides and then in between the chief ones, and soon all had merged into a single pillar of uprushing fumes, issuing more and more copiously and rising to higher and higher altitudes. By 7:45 (Plate II, *a*) the diameter of this column had thus increased to more than a mile, where a little earlier the total width including the clear space did not exceed 3,000 feet. The column had now reached a height of 15,000–18,000 feet above the mountain profile. Its stem resembled a huge column fluted with drapery hung in simple vertical folds. The cumulus crown still showed a double head, and thus continued to indicate the positions of the two dominant fume columns which, in reality, persisted throughout

[1] These views—12 (14) in all—were made on Wratten Panchromatic M plates, quarter-plate size, through a K_2 filter and a Zeiss Double Protar lens, F = 13 cm., with a stop of *f*45. Time exposures of about five seconds were made with the earlier views; but, with increasing actinicity, the later exposures were clipped a little short.

the outbreak. Also a smoke ring is shown encircling the upper part of the column below the crown. By eye observation the writer did not notice this ring until about 7:50 A.M. Despite this he feels confident that it had not begun to form when he first saw the eruption cloud.

After 7:50 A.M. the form of the eruption cloud underwent rapid changes as the continued emanation of fumes added to its bulk, and convection currents and varying winds at different altitudes continually reshaped it. At 8:00 A.M. the diameter of the stem had increased to from $1\frac{1}{2}$ to $1\frac{3}{4}$ miles and the smoke ring, which had rapidly enlarged, had begun to fray and spread horizontally about equally in all directions, except for a slight elongation toward the northwest, forming the striking mushroom shown in Plate II, *b*. By this time the crown had reached a height of 20,000 feet, or more, above the mountain profile, and its tip was just beginning to fray in the upper wind.

At a little after 8:00 A.M. the uprush of fumes began to dimish, and by 8:30 the two dominant columns were again separated, and the subordinate columns had ceased to rise continuously. The fume cloud had spread rapidly at the level of the smoke ring, forming a cloud blanket, and this, with the fraying and drift to eastward from the summit of the crown, gave rise to the beautiful cloud-form shown in Plate II, *c*. This has been likened aptly to a ballet dancer. The emanation of fumes continued to diminish rapidly, as is emphasized in the view (Plate II, *d*) taken at 9:05 A.M. Only a graceful cloud-form then remained, with thin columns of rising fumes.

By 10 A.M. (Plate III, *a*) it required keen observation to detect any further output of fumes; and by 10:30 this could be made out only by experienced eyes. By 11:00 A.M. the action was doubtful, and it grew more and more doubtful afterward—though cloud-forms occasionally appeared where undoubted fume columns had been rising. By noon nothing could be seen but a frayed stratum of high cloud overspreading the sky above the mountain. This exhibited ripple-marking, like cross-waved cirrus. It persisted until after sunset.

From about 8:30 A.M. on, short-lived, subordinate columns, wisplike in appearance, were noted at points a little higher up the slope than previously and at points much farther down the slope also, over a span from five to seven times as great as the width of the fume column at its greatest. These lateral columns did not persist individually, and gradually they ceased to appear.

Until the smoke began to fray and spread out like a blanket, the columns of upcurling fumes were fleecy white in appearance in the bright morning sun, with cream tints also, like cumulus cloud; and so too was the cumulus crown. As the blanket spread, however, it shadowed first the column and then its own lower surface, so that these shaded portions took on a faint, graduated coloring in which brownish and purplish tones of a faded-out quality were commingled with various shades of gray. This coloration developed quickly with the horizontal outspread of the fumes. No truly dark-colored fumes were seen.

After the cumulus crown had risen into the upper air and had begun to fray and drift eastward, such action continued until the lessened emanation of the fumes brought it to an end, late in the forenoon. Altogether, however, only a small percentage of the fumes reached the uppermost levels. Most of the drift was to the northwestward. By 8:00 A.M. this tendency for the horizontal fume-cloud blanket to draw out in the northwest direction was noted. By 9:30 the drift in this direction of the blanket as a whole had become noticeable, and by 10:30 such shifting was marked. This spreading and drift of the cloud blanket to the west and northwest until it stretched out back of the mountain profile, so as to extend below the skyline, made a cloud-colored background against which were rising the cloud-colored fumes, slightly tinted with brown. This made the fuming very hard to see, but there is no doubt of its rapid and progressive diminution after 8:00 A.M. During the afternoon no rising fumes were seen definitely. But for a very short time, just at sunset and after, very thin, translucent fumes were seen, brown in the transmitted light of the western sky.

In the early evening there was cloud and mist intermittent with brief, clear glimpses. From the observatory no definite glow could be seen, but there appeared to be a very faint radiation of

light over the dark sky from a point on the slope near the place of outbreak, though apparently a little lower down. That this emanated from the eruption was, and is, doubtful. It was too faint to be a positive illumination. However, it is the understanding of the writer that a faint glow was seen that night by Captain Nicholson when off Fisherman Point. This and subsequent events strengthen the probability that the faint light seen from the observatory was, in reality, from the eruption.

From the observatory no fumes were seen on the 20th, nor early on the 21st. From Kealakeakua, however, a "pillar of smoke" was seen early in the morning of the 20th by Miss Paris, a lifelong resident of Hawaii, familiar with the appearance of the mountain profile and with the characteristics of eruption here. This appeared high up on the south slope as seen from Kona. From the observatory, just at sunset in the evening of the 21st, thin brown-toned fumes were seen by transmitted light rising from near the place of outbreak. They appeared somewhat more pronounced, even, than on the evening of the 19th.

A small amount of lava probably was ejected at the time of this outbreak. This was reported as seen by men high on the slopes back of Naalehu and Kahuku, and in Kona, but the action was quickly over.

As mentioned earlier, the swarm of earthquakes which preceded and accompanied the first uprush of fumes was followed by a lull in the registration of shocks, of less than twenty-four hours' duration. After this they began to register in greater number than before, and in most instances with greater amplitude also. Intervals of quiet were short. The resumption and continuation of this seismic activity led to expectation of the outbreak of flow. Flow broke out, considerably lower down the slope than the place of first outbreak, in the late evening of May 21. With little doubt it was first seen by the writer, at about 11:15 P.M. It was at once brought to the attention of others at the Volcano House near by, and from here the news was spread by telephone on the eastern side of the island. On the western side of the island the outbreak was first noticed a little before midnight by Mrs. McWayne, and there the news was similarly spread.

Probably the outbreak was noticed by the writer almost as soon as it occurred. The night was clear, except for a low bank of clouds at the northeast. At 10:00 P.M. and earlier there was no suggestion of illumination anywhere along the southern segment of the mountain profile. At about 11:15 P.M. the writer went from the Volcano House to the observatory to see that the seismographs were in good working order before retiring (for, owing to the frequency and energy of the shocks, there was likelihood of the disarrangement of the struts and levers). The moon had just risen, but it was still hidden behind the bank of clouds at the northeast. However, a faint, diffuse moonlight spread over the sky. Upon mounting the observatory porch a very faint light was seen radiating from a point behind the mountain profile much lower down the southern slope than the place of first outbreak. The effect was similar to that sometimes produced here just as a planet or a bright star drops below the mountain profile. After inspection of the seismographs, however—perhaps three minutes later—this radiating light had become more definite, although the illumination of the sky by the moon had grown brighter. Almost at once it took on a pinkish hue. Then the word was spread instantly. Judging by the rapidity of its development in the first ten minutes after it was discovered, the outbreak did not take place (or more strictly, become visible from the observatory) earlier than 11:00 P.M., and probably not earlier than 11:10 P.M. Its discovery was little later than its occurrence.

During the ten or fifteen minutes after it was first seen the light at the fountainhead grew rapidly, and a small diffuse cloud of fumes appeared. This increased quickly also, and the glow steadily grew brighter and more ruddy. Soon the fumes at the top began to drift to the northwest up the mountain slope behind the profile. At the same time the progressive extension of a faint ruddy illumination down the slope behind the profile was detected. Flow had begun. As soon as possible, at about 11:45 P.M., the director of the observatory, Professor T. A. Jaggar, Jr., and the writer set out by motor and proceeded southwestward and westward to a point near the boundary of the Kona district of Hawaii beyond the western branch of the flow of 1907—a distance of about

sixty miles—and back again, arriving at the observatory at about 6:45 A.M., May 22. West of the village of Waiohinu several stops were made, both going and returning, to observe and photograph. All along the way from the observatory to the turning-point, and back again, a gradual and steady increase was noted in the height, amount, and spread of the fumes; and, until dawn, in the brilliancy of the illumination at the fountainhead. A well-defined northwest drift of the fumes in the upper strata of the air gradually developed.

From the upland flats along the road near Kahuku, and points to the westward, a long line of faint reddish illumination was seen extending to the right from the fountainhead. The course of this was judged to be about south-southeast from the source. At first it was considered to be light from the surface of a pool, but as it elongated rapidly it was soon thought to be a line of illumination above a flowing stream. This opinion was confirmed by a visit to this flow made later in the day by Messrs. J. W. Waldron and T. Hardy.

At about 4:00 A.M., May 22, we met Mr. Samuel Kauhane at the roadside gate of the ranch house at Kahuku—a man to whom the south slope of Loa was well known—and he expressed the opinion that the outbreak was higher up the mountain than the group of old cones at Puu o Keokeo. This proved to be the case.

Upon our return to the observatory a photograph (Plate III, *b*) was made at 8:30 A.M. (as early as weather conditions would permit), to show the position and development of the fume column and crown rising above the fountainhead. This view should be compared with Plate II, *a* to gain an understanding of how much lower down the mountain than the place of earlier outbreak the place of later outbreak is situated. The true azimuth from the observatory of the apparent center of this fume column at the source was found to be about S. 66° W. (the azimuths of the upper and lower limits of the greater column of the earlier outbursts were approximately S. 82° 30′ W. and S. 85° 30′ W.). This azimuth, projected upon the government map, indicated a source low on the southwest flank of the mountain, and, assuming this source to lie in the line of the south-southwest rifting from summit to sea, it was near the line of the upper branch of the flow of 1907 at an

altitude of 6,500 feet—as shown approximately on the government map—a little above Puu o Keokeo. This location was confirmed by field survey, though multiple mouths were found along a linear rift at the source, and the altitude was found to be a little higher than 6,500 feet at the lowest point of the actual source. The region of the fountainhead thus is between 30 and 35 miles west-southwest from the observatory.

In contrast to this, the region of the earlier outburst, determined by projecting the azimuths given above, is intercepted along the course of the great rift-line between approximate contour lines drawn on the government map, as follows: the upper and lower limits of the great trunk column of uprushing fumes are thus indicated at about 11,600 and 11,000 feet above sea, and the diameter of the column is thus indicated at considerably over a mile; similarly, the *approximate* upper and lower limits of the span marked by subordinate sporadic columns of rising fumes may be taken as 12,000+ and 10,000− feet, determining the width of this at five miles, or more. All these are approximate values. Nevertheless, this source is thus found to stand higher up the mountain than the early estimates placed it.

In the late afternoon of the first day of eruption, May 22, the writer returned to the southern part of the island, and spent the evening and night in observing the changes in the magnificent illumination from places along the road over the upland flats west of Kahuku. This locality was reached just at nightfall; it was then cloudy, with brief showers; however, before long the clouds lifted, though they continued to cover the sky. Little by little the character and extent of the illumination became visible.

Since the dark hours of the morning a great change had taken place. At the fountainhead both the action and the illumination were somewhat greater than when last seen in the early morning, but here the change was least. The faint red illumination extending toward the right (toward Waiohinu over upland Kahuku) had died out. But toward the left, toward Kona, a long line of brilliantly illuminated fume and cloud demarked the course of a flow which had rushed down the mountain toward Honomalino. In early evening this was still advancing at a considerable rate. The

marked illumination, which we may designate as the primary glow, was most brilliant at the fountainhead, and above the front of this flow (where its outflashing was augmented by the light from the burning forest); but also above the course of the flow between its front and source the glow was much brighter than the general sky glare. This formed a band of primary illumination whose length, as seen from the gate about a mile west of the ranch house at Kahuku, was very close to seven miles; and its brilliantly lighted arch rose about three-quarters of a mile above the mountain profile (Plate III, *c*).

A diffuse red glow covered the sky everywhere and, in early evening, low-lying cloud and fog banks clinging to the mountain slopes below the road, and illumined dimly by reflections from the cloud layer above, led to a current erroneous opinion that the flow already had advanced down the slope beyond the road in Kona.

Owing to the wretched state of the road surface, a serious congestion of motor traffic (some 250 motors headed westward and about 80 headed southward, toward a meeting-point near Honomalino, on a road too narrow for passing or turning except at widely separated places), and much uncertainty as to the exact course, rate, and behavior of the flow, the writer spent most of the night at a gate on the road about a mile west of Kahuku, where he returned after going to within three to four miles of a group of houses at Honomalino which stood in the apparent path of the flow.

The photograph (Plate III, c^1) shows the scene from this station as it appeared just before midnight, May 22. In this view, of course, the bright reddish glow which covered all the sky does not appear, but simply the brilliant arch of the primary illumination, as designated above. During the night the following changes were observed:

A little after midnight there was noticed a rapid spread of very brilliant glow to the right of the fume column rising at the fountainhead. This was a conspicuous feature of the action until after 1:00 A.M. It was thought to indicate a flow toward Kahuku. This

[1] Made on a Wratten Panchromatic M plate exposed 30 minutes at *f*/6.3.

judgment was confirmed by Messrs. Waldron and Hardy, who witnessed its outrush from the high camp they occupied that night.

Beginning gradually, probably before midnight, certainly as early as 1:00 A.M., there was noted a rapid decrease[1] in the brillancy of illumination above the line of flow extending toward Honomalino. By 3:00 A.M. this, as seen from our station, was quenched completely; there remained only the diffuse glow of the clouded sky and the brilliantly lighted column of fumes rising at the fountainhead, and a much subdued glow above the front of the flow. And this last was decreasing rapidly. By 4:00 A.M. the earliest light of dawn found the illumination at the fountainhead much like that of the previous morning, with the lines of illumination above the courses of flow almost wholly quenched.

Shocks of earthquake continued to occur. Some were strong enough to disarrange the struts and levers of the seismographs. This made it inadvisable for the writer to be absent from the observatory except at times when the director could be present; so, after a brief visit to the front of the Honomalino branch, the writer returned to Kilauea.

During the evening and night of May 23–24 it was seen from the observatory that the glow had extended far to the left of the fountainhead in a direction estimated at south-southeast. No such extension of the band of illumination had been seen in the evening or night of May 22–23. This was due to the renewal of flow toward Kahuku on a much larger scale than in the beginning. Ultimately the Kahuku branches developed much greater magnitude than those in Kona. During this evening and night, May 23–24, this glow was seen through shifting clouds, so that no good opportunity for making a photographic record presented itself in the earlier hours. And, owing to his complete loss of sleep on the two previous nights, the writer undertook no prolonged watch. During the evening and night of May 24–25 this illumination appeared elongated farther to the south, and perhaps slightly abated in intensity. A photographic record of this (Plate III, *d*)

[1] It should be noted that moonrise occurred between midnight and one o'clock, but that this decrease in illumination was positive, nevertheless, as evidenced by the glow above the Kahuku tongue.

was obtained in the early morning hours of May 25, from 1:15 to 1:45 A.M. In a lessening degree this glow was seen in the evenings of May 25 and 26, and very faintly on the evenings of May 27 and 28. On the latter date it was near to the vanishing point.

II

The writer reached the front of the Honomalino branch of this flow at about 11:00 A.M., May 23, at a point about three miles, by trail, above the road. Here the flow was of *a–a*, still advancing at a slow rate of speed. This was difficult to estimate on account of the irregular character of the ground and the brief time available for watching. Though moving much more slowly than earlier, the advance was still steady. Possibly the maximum forward movement of any considerable section of the front was ten feet in an hour. The average over the whole front was less, perhaps four to five feet in an hour. At this front the flow was narrow, not more than a quarter of a mile in width. The depth at the front was variable, from six to ten or fifteen feet. Its surface, both on the top and at the front and sides, was bristling with ragged points and edges of brownish-black *a–a*. In this surface were innumerable cracks, mouths, and ovens through which the red-hot matter shone out. From many of these blue flames were flaring fitfully.

According to the writer's observation, carefully concentrated on this point, its mode of flow at this stage was as follows:

At the front, between the top and bottom, there was a slow, forward, bulging motion of the intermediate layer, from four to ten feet thick. As this progressed it produced fragmentation of the thick, stiffened surface over it, pulling and breaking this away from its contiguous parts at the more slowly moving top and bottom, and also breaking it up into an irregular mosaic with the changing curvature of the surface of the front. At short intervals blocks of the fragmented surface would be rotated into unbalanced positions, when they would spall off from their own weight and drop to the foot of the front, leaving for a moment bright, red-hot scars where they had scaled away from the matrix within. Repeated examination of these scars showed continuous red-hot matter of very viscous consistency, which cooled very quickly, tending only to

bulge out a little without spurting or jetting. No cracks could be made out on these freshly bared, red-hot surfaces. They exhibited every appearance of a viscous continuum. Once they had crusted over, however, the tendency to crack and bristle again became noticeable. At this place the fragmentation and texture-forming of these rough-surfaced blocks suggested very strongly the breaking and cracking of candy pulled too long. There was no observable gas action.

The whole effect here was one of creep, or overrunning, with the plane of maximum rate of flow intermediate between the top and the bottom. The action was that of a very viscous, fluid or plastic, substance, flowing very slowly and exerting subsurface traction upon a surface crust too stiff to *draw* or *pull* much.

It is thought that the matter was here cooled to a point where it could still flow, or creep along, under blanketing, but once in touch with the air it set so stiffly that any further strain fragmented it. Pieces artificially broken away from the bulging surfaces cooled without further fragmentation, and without the development of *a–a-texture*[1] on those surfaces of the fragments which were glowing when broken away. These exhibited the rough fracture of cold basalt. The rough, pointed, and edged texture of the natural *a–a* surface was *seen* in some cases to be due to the drawing out of points and the shaping of rough edges as the blocks were tilted and rotated away from each other, and from the plastic matrix within, while the forward bulging movement was taking place.

The mechanism of the formation of *a–a* has been considered a very involved and complicated process, and the problems suggested by it difficult of solution. The writer does not consider that the observed action described above will serve to explain all cases and details. But it does, he considers, indicate strongly that *a–a*

[1] A word concerning *a–a-texture* may not be out of place. As seen in Hawaii *a–a* is not only block-lava, heaped flows of piled blocks and fragments of various shapes and sizes, but each of these fragments is a separate unit, and its whole exterior surface, in most instances, is characterized by an exceedingly rough aggregation of points, edges, blades, spikes, knobs, etc., produced there in the process of the spalling and transport of the blocks by the *drawing*, and possibly sometimes by spurting, of the red-hot viscous basalt.

generally results from fragmentation or granulation in the course of flows of lava grown too stiff for further plastic flow under the prevailing conditions—whether this results from rapid cooling due to rapid escape of gas, to slow cooling, or to stiffening due to the development of crystalline phases, throughout the mass, or in lumps so as to form a sludge. The time is not ripe for discussion and comparison of all these factors and their interrelationships.

But the action described above, with suitably conceived modifications applicable in the region of more rapid streaming, and where greater masses and higher temperatures are involved, appears to the writer to be capable of explaining *most* of the vagaries of surface texture and miniature surface forms exhibited by *a–a* in Hawaii. Everything that the writer has seen in connection with this outbreak, and all the reports that have come to his attention, indicate that there was no *excessive* evolution of volcanic gases from the molten lava on this occasion; and all indications are that the temperature of the melt has not been excessively high. This points to a *relatively* cool and viscous fluid. And so far this supports the view of its action sketched here. It is, of course, not unlikely that still other mechanisms are involved in the forming of *a–a*, and emphatically there is no disposition to question any which rest upon observation or sound rationale. However, to the writer it seems unnecessary to appeal to unobserved, recondite, special mechanisms to explain the fragmentation and textural qualities of *a–a*. This view is in accord with the tenor of a view expressed to the writer by Dr. William T. Brigham, of the Bishop Museum in Honolulu, that *a–a* is the slush ice, or floe ice, in a cooled and freezing stream (the granulation by motion of a stiff, overcooled fluid on the point of solidifying). This seems the best short expression of the idea.

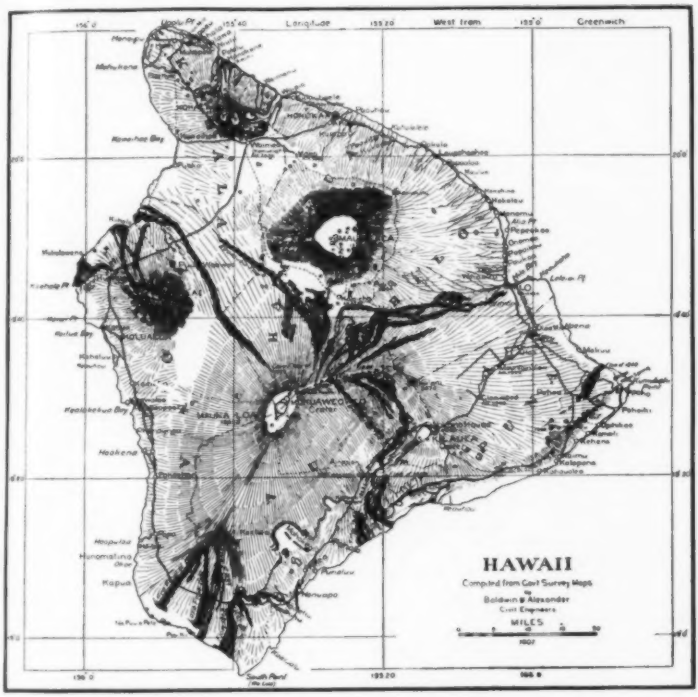
The writer saw the action just as the stream had slowed up, almost undoubtedly on account of failing supply at the source of this branch. Thus the failure of pressure from above and the radiation of heat all along the course led to rapid increase of sluggishness. At this stage of the flowing there was practically no gas action at the front. Blue fumes were rising from the surface, along with heat-disturbed air, but these were so thin that from a

tree near the front the writer was able to look a long way up the flow. The only hindrance to good seeing was the shimmer of the air produced by the heat radiation. The surface showed many oven-like openings, and a few small conelike forms were seen, but these were of temporary nature, and not true cones. No explanation of their formation occurred to the writer. One that was watched was slowly destroyed as the forward motion progressed.

The falling blocks made a tinkling sound, and the forward motion of the upper surface was accompanied by a low grinding sound, but these noises were low and inaudible at a short distance. The quiet character of the advance at this stage was very striking. At intervals loud detonations were heard. These were ascribed to the action of the hot lava on buried vegetation. The sounds made by the crackling of the falling trees and bushes were the loudest of the frequent noises, and the crackling produced by the burning of green vegetation was the most continuous and conspicuous. At this stage of the flow its approach was so quiet that it gave practically no warning at a distance of fifty yards. Trees were being felled by the flow, partly by burning through at the stump, but in some instances by overturning as a result of the forward motion of the flow.

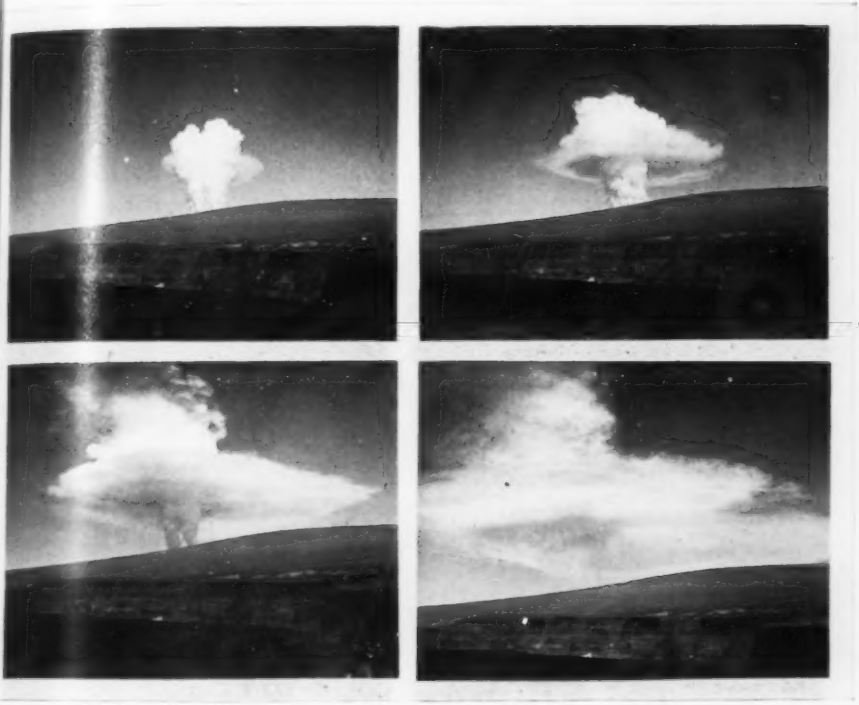
There were smells of subliming sulphur, sulphur acids, and of cinders and charcoal. None of these was strong enough to be very annoying. Others reported the smell of coal gas. This was not noted by the writer, but was noticed by a large number of people, and the fact must therefore be accepted. This was in the wooded region, and here these carbon-gas odors could be ascribed to the action of the lava on vegetation. However, along the Kahuku branch of the flow such carbon-gas odors were plainly noticed by many at points well above the wooded region, where vegetation was so scanty as to be negligible. And some have reported noticing these odors near the lower end of the source in a barren region where there is strictly no vegetation. It seems, therefore, that carbon gases almost unquestionably were emitted from the lava of this eruption.

[*To be continued*]



Map of Hawaii, showing *diagrammatically* in red the flow of 1916, and the upper outbreak source, with older flows in black. On this map the upper portion of the flow of 1907 is not indicated *precisely*. This passed down the mountain on the west side of Puu o Keokeo.

a *b*



c *d*

Views *a*, *b*, *c*, and *d* show successive stages in the development of the fume cloud [*a* at 7:45, *b* at 8:00, *c* at 8:30, and *d* at 9:05 A.M.] of the earlier outbreak on May 19, 1916, as seen at a distance of about 25 miles, in a direction a little south of west, from the Hawaiian Volcano Observatory.

a *b*

c *d*

a, showing a later stage, at 10:00 A.M., in the spread of the fume cloud of May 19, 1916.

b, showing the fume cloud above the head of flow at 8:30 A.M., May 22, 1916, as seen at a distance of 30–35 miles, in a direction S. 66° W. from the Hawaiian Volcano Observatory.

c, showing the brightly illuminated arch, or "primary glow," above the source, and the course of the Honomalino stream, as seen just before midnight, May 22, 1916, at a distance of about 10 miles in a direction about N.N.W. from near Kahuku. This illuminated band or arch was about 7 miles in length and about 1 mile in height. Besides it, a bright, diffused red glow covered the entire clouded sky—an effect not shown by the view.

d, a view from the Hawaiian Volcano Observatory exposed from 1:15 to 1:45 A.M., May 25, showing the illuminated fume cloud above Kilauea (lower left) at a distance of 2¾ miles from the camera, of about 1,500 feet spread, and the illumination above the Kahuku stream (upper right), partly hidden by clouds at the south, distant 30–35 miles, with a spread of about 5 miles and a height of a little less than 1½ miles at maximum.

AGE AND STRATIGRAPHIC RELATIONS OF THE OLENTANGY SHALE OF CENTRAL OHIO, WITH REMARKS ON THE PROUT LIMESTONE AND SO-CALLED OLENTANGY SHALES OF NORTHERN OHIO

AMADEUS W. GRABAU
Columbia University

The name "Olentangy shale" was given by N. H. Winchell[1] in 1874 to the light-gray soapy shales which underlie the Ohio shale and are exposed on the Olentangy River and its tributaries in central Ohio. Winchell regarded this shale as belonging with the Huron shale which overlies it, but since his day this deposit has usually been classed with the Middle Devonian,[2] and has been made in a general way the equivalent of the Hamilton formation of New York. The reason for such a grouping seems to have been the fact that in northern Ohio a shale and limestone series lies between the Huron shale and the Delaware limestone and so holds essentially the position occupied by the Olentangy shale in central Ohio. I have elsewhere[3] proposed to call this series in northern Ohio the Prout series, from its exposures near the station of that name. In the summer of 1914 I made a detailed study of the several outcrops of this formation in the region about Sandusky, collecting at Plum Creek and paying special attention to the contact of the Prout and Huron formations shown in the exposures at Slate Cut on the Lake Shore Railroad, halfway between Sandusky and Huron, and in the "Deep Cut," about a mile northeast of Prout Station. A summary of my observations was included in the *Report on the Devonic Formations of Michigan* submitted toward the end of that

[1] *Geol. Surv. Ohio*, II, Pt. 1, pp. 287–89.

[2] The author prefers the term "Devonic" to "Devonian," but has changed it in conformity with the usage of the *Journal*.

[3] "Olentangy Shale of Central Ohio and Its Stratigraphic Significance" (Abstract), *Bull. G.S.A.*, XXVI (1915), 112.

year, but unfortunately not yet published. I quote from the manuscript:

> The upper 4½ to 5 inches of the Prout has a peculiar character in that it is full of pyrites, is irregularly bedded, and contains much glauconite. Black shale specks and fish teeth are found in the upper half-inch. This upper part of the limestone suggests a weathered and reworked portion very different from the lower part, which is also dolomitized. Some doubtful limestone pebbles have been found at the contact line in the base of the Huron shale, but they are not sufficient in number to be of much value. Altogether, the evidence is inconclusive, but it is not against the assumption of a disconformity [between the Prout and the Huron]. . . . .

The abrupt contact and the absence of intergrading are further indications of a pronounced change in sedimentation with a long time interval between the two formations. A comparison of the fauna of the Prout with that of the Traverse group of Michigan, gone into at some length in my report, shows the former to correspond to the lower Traverse of Michigan, i.e., to the beds below the Alpena limestone. I quote again from my manuscript report:

> This means that the upper beds were never deposited or that they were removed by erosion prior to the deposition of the black shale, for no one would consider the black shale in any way contemporaneous with the upper Traverse beds of Michigan. Thus an unquestioned time interval is indicated, and since we find elsewhere the black shale disconformable upon the Traverse or other Mid-Devonic beds, we need not hesitate to assume the same relation for northern Ohio. . . . . Compared with the sections in northwestern Ohio and in Canada, the evidence becomes quite conclusive that between the Prout and the Huron there is an unrecorded time interval.

Quite recently Dr. Stauffer[1] has returned to a discussion of the correlation of the Prout formation on the basis of its fossils, which he listed in an earlier publication.[2] He comes to the conclusion that the Prout limestone represents the Encrinal limestone of Eighteen Mile Creek,[3] and the shales below it, the lower Hamilton shales of western New York.[4]

[1] C. R. Stauffer, "The Relationships of the Olentangy Shale and Associated Devonian Deposits of Northern Ohio," *Jour. Geol.*, XXIV, No. 5 (July-August, 1916), pp. 476–87.

[2] *Geol. Surv. Ohio. Bull. No. 10*, 4th Series, 1909.

[3] I have proposed the name Morse Creek limestone for this Encrinal of western New York at the meeting of the Geological Society of America, December, 1914, and in the report on *The Devonic Formations of Michigan* above referred to. It is an older limestone than the Encrinal or Tichenor of central New York. See *Bull. G. S. A.*, XXVI (1915), 113.

[4] Now designated the Wanakah shales by me.

That exact correlation with the Encrinal limestone of Lake Erie is possible may perhaps be doubted, since the calcareous beds increase in number westward. The Encrinal (Morse Creek) limestone is the attenuated eastward extension of the great Alpena limestone of Michigan, and the Prout limestone probably represents one of the lower Traverse limestones of Michigan. Still, Stauffer is undoubtedly correct when he makes the age of the Prout limestone and associated shales lower Hamilton, and it is gratifying to me to feel myself in substantial agreement with one who has made such prolonged studies of these formations and faunas.

When it comes to the Olentangy shale of central Ohio, however, Stauffer and I are in cordial disagreement. He makes it the equivalent of the Prout limestone and shales of the north and so of Hamilton age, while I regard it as a part of the Huron shale series, and referable to the Upper Devonian.

Although I had held this view for many years, it was not until the summer of 1914 that I was enabled thoroughly to test my conclusions in the field. At that time I examined all the important exposures of the formation in Delaware County, beginning with Winchell's type locality, on the Olentangy River. A new section opened here for commercial purposes made a careful study possible. The actual contact between the Olentangy and Huron is sharp, but perfectly even and uniform. In the upper portion of the gray Olentangy are several thin bands of black or chocolate-colored shale of the type of the Huron.

The bedding of the Olentangy shale is chiefly brought out by the occurrence of thin bands of dark shale, and by more or less continuous layers of flat concretions. These are calcareous, up to 2 feet long by 1 foot thick, but mostly smaller. They abound in iron pyrites, as does also the Huron shale overlying. In some sections, as in the Deep Run and Lewis Center and Bartholomew runs, the lower part of the Olentangy shale contains thin bands of impure limestone. In one of these I found fish scales. In all the sections, however, are found the thin bands of black shale in the upper part of the gray, thus indicating a transition of the one formation into the other. At the contact with the first great mass of Huron shale there are sometimes found indications of a slight drying of the surface of the Olentangy, with the formation of cakes

or scales of dry, gray mud, which were then incorporated in the black mud. This is just what we should expect if the deposition of the gray muds had come to an end and sedimentation were renewed by the influx of the black mud from another source. Essentially, however, deposition here was continuous, and after the commencement of the sedimentation of the black Huron mud, there was a temporary recurrence of the gray sedimentation, so that we see today a 10-foot bed with all the characters of the typical Olentangy lying above a considerable thickness of black Huron shale. In both the upper and the lower part of this interbedded mass of Olentangy occur thin bands of black shale, as they do in the typical Olentangy lower down.

The basal contact of the Olentangy and Delaware is not shown in any section which I visited, but the Olentangy could be examined to within a few feet of the contact. There is no interbedding of the Delaware and the Olentangy; the change in material is absolute. The concretionary limestones of the Olentangy are very different in character from the calcarenytes of the Delaware limestone. The concretions appear to be of the subsequent type found in the gray Cashaqua shales of western New York, to which the Olentangy shales bear the closest resemblance. Like them, they are unfossiliferous, though fossils are found in some parts of the Cashaqua. The barren nature of both of these shales is in striking contrast with the highly fossiliferous character of the Hamilton shales of western New York, Canada, Michigan and even northern Ohio. A few fragmentary fossils have been found in the calcareous beds, but these might easily be residual specimens weathered from the underlying limestones and incorporated in the new sediment. Such undoubtedly is the origin of the lenticular bed of crinoid fragments found in the type section, which does not exceed 5 inches in thickness. This is apparently a reworked mass of crinoidal fragments dissociated by the weathering of an older crinoidal limestone.

The relationships here presented admit of only one conclusion, namely, that the Olentangy shale is a part of the Upper Devonian, representing a special type of sedimentation, such as characterized the early Upper Devonian sediments of western New York. Sedi-

mentation was continuous from Olentangy into Huron time, but the Huron type alone is represented in northern Ohio, where by overlap it rests upon the eroded surface of the Prout limestone. The latter is absent in central Ohio, where either it was never deposited, or, what is more likely, it was removed by pre-Huron erosion. This erosion extended down to the Delaware limestone, though it is not impossible that a part of the lower Prout series is represented in the central area by the Delaware limestone itself. If the name "Prout" is to be restricted to the limestone member of the northern series, then the shale below it must receive another name. It certainly is not Olentangy, which name belongs to the earliest Upper Devonian formation of central Ohio. In my report on *The Devonic Formations of Michigan* I have proposed the name "Arkona beds" for the shales lying below the Encrinal limestone of the Thedford, Ontario, region. If, as Stauffer holds, the shales below the Prout limestone are the equivalent of these Ontario shales, which he calls Olentangy, then the name "Arkona" may also apply to them. It may be wiser, however, to refer to them as the Plum Creek shales, since the distance between Arkona and Plum Creek is too great to permit of positive identification. True, Dr. Shimer and myself correlated the Encrinal limestone of Thedford with that of western New York, on the basis of faunal characters, and this correlation may be correct. At the same time, we now know that the Encrinal of western New York (Morse Creek) and that of central New York (Tichenor) are not the same beds. I have also shown[1] that the faunas of the shales below the Morse Creek in Eighteen Mile Creek occur in the shales above this limestone 60 miles to the east, where they are not found below that limestone. I have also shown that this typical Hamilton fauna is absent from the beds above the Morse Creek limestone at Eighteen Mile Creek, there being thus a complete inversion of faunas. On purely faunal grounds the shales below the Morse Creek at Eighteen Mile Creek would be correlated with the shales above that bed at Moscow and elsewhere in the Genesee Valley. The explanation of this and the relation of the western New York Hamilton faunas to the Thedford and Michigan Traverse

[1] "The Faunas of the Hamilton Group of Eighteen Mile Creek and Vicinity in Western New York," *16th Annual Report, N.Y. State Museum*, 1898, p. 330.

faunas is fully set forth in the unpublished report referred to. There, too, it is shown that the faunas of the Traverse group on opposite sides of the state of Michigan differ materially, while identification of equivalent limestones and shales between the two sections is impossible. All of these facts would lend some force to the suggestion that precise correlation of the Prout limestone and Plum Creek shales with the Encrinal limestone and Arkona shales of the Thedford region should not be too rigidly insisted upon. Nevertheless, we may with Stauffer lay much stress on the presence of the *Bactrites* layer at about 25 feet below the Encrinal at Arkona and a similar distance below the Prout limestone at Plum Creek,

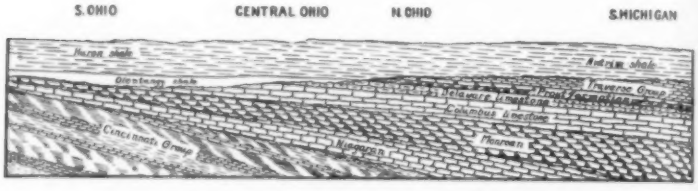


FIG. 1.—A generalized north-south section through Ohio and southern Michigan, showing the relations of the Olentangy shale and the Prout formation.

containing at both places pyritized *Bactrites arkonensis* and *Tornoceras uniangulare*, besides *Nucula triqueter* and *Leda rostellaria*. Then, too, as Stauffer has shown, the faunas of the Prout limestones of this and of the Encrinal of Ontario are very similar, the latter containing over 75 per cent of the species found in the former. On the whole, therefore, Stauffer's position seems well taken, and we may accept his correlation of the Prout limestone with the "Encrinal" of Thedford and perhaps with the Encrinal (Morse Creek) of western New York.

We cannot, however, use the name Olentangy for the shales below these horizons, and therefore the Canadian term "Arkona shales" is preferable. This name may be then applied likewise to the shales of Plum Creek. The comparative study of the brachiopods of these various shales, now in process, will throw further light on the provincial relationships of these formations.

Let us return once more to the typical Olentangy shale of central Ohio, which we have seen is of Upper Devonian age. It rests disconformably upon the Delaware limestone, which represents some of the lower Traverse beds of the Michigan region. There is thus a great hiatus between the Delaware limestone and the Olentangy shale in central Ohio, cutting out the greater part of the Traverse group. This hiatus increases southward, so that in Pickaway County the Olentangy shale lies in places upon the lower Columbus and elsewhere upon the Monroan, and in all cases it is succeeded by the black Huron shale. At Bainbridge, in Ross County, it even rests upon the Niagaran. The Olentangy is still represented at Vanceburg, Kentucky, on the Ohio River and near Fox Springs, Fleming County, Kentucky, according to W. C. Morse. A generalized north-south section through the region named brings out the magnitude of the post-Traverse erosion, and also shows that the Olentangy shale is of the nature of a lentil, disappearing to the north and to the south. The source of the Olentangy was probably local and circumscribed, representing perhaps an accumulation in Upper Devonian time of a residual soil produced from the weathering of the underlying rocks. It may possibly be an extension of some of the eastern gray shales of the Upper Devonian, such as the Cashaqua. The Black Huron shale I hold to be a deposit of carbonaceous mud washed into the shallow Upper Devonian sea by the rivers coming from the Devonian peneplanes to the south and representing probably our best case of an estuarine deposit in the American Paleozoic. The details of this and the relation of the Huron to the Chattanooga shale, which latter I consider mostly a terrestrial residual soil, reworked in Mississippian time by the encroaching sea, are set forth at length in the monograph on *The Devonic Formations of Michigan* to which reference has several times been made.

THE HISTORY OF DEVILS LAKE, WISCONSIN

ARTHUR C. TROWBRIDGE
University of Iowa

The vicinity of Devils Lake, Wisconsin, has long been used as a field of instruction in geology in the Middle West. The pre-Cambrian igneous, sedimentary, and metamorphic rocks, the Paleozoic history, the economic products, the general results of glaciation, the origin and history of the lake, have all been reported in a general way.[1] It has been the privilege of the writer to conduct several courses in the district, to work over the data collected and reported by previous investigators, and to work out additional points not completed by them. He finds that the general history of the district may be incorporated in an account of the history of the lake and its basin.

The purpose of this paper is to bring together all the events in the history of the lake basin, and to include some heretofore unpublished conclusions as to the history of the lake, its past and present sources of supply, and outlets once established but now abandoned. This involves repetition of some facts already published, and leads beyond the present boundaries of the lake basin.

LOCATION AND DESCRIPTION

Devils Lake is an almost rectangular body of fresh water $1\frac{3}{10}$ miles long in a north-south direction and $\frac{1}{2}$ mile broad, situated in Sauk County, Wisconsin, 3 miles south of Baraboo, 40 miles north by northwest of Madison, 80 miles southeast of LaCrosse, and 100 miles west by northwest of Milwaukee.

The district in which the lake lies is one of extraordinary high relief for the central Mississippi Basin (about 800 feet) and of considerable irregularity. The topography is dominated by two

[1] R. D. Salisbury and W. W. Atwood, *Bull. No. 5, Wis. Geol. and Nat. Hist. Surv.*, pp. 51–55; Samuel Weidman, *Bull. No. 13, ibid.*, pp. 109–14; Lawrence Martin, *Bull. No. 36, ibid.*, pp. 177–78.

ridges or "ranges," known respectively as the North Range and the South Range. These are the outcropping edges of the hard Baraboo quartzite formation which forms here an asymmetric syncline, the north limb of which is nearly vertical and forms the North Range and the south limb of which has an average dip of 18° and forms the broader and higher South Range. The ranges are 24 miles long in a general east-west direction, and they converge at either end. The South Range is distinctly flat at and near the top, the plain summit areas lying between 1,400 and 1,480 feet A.T. There are also smaller areas of flattish land at 1,200 feet, 400 feet below Sauk Point, which is the highest point in the district, and 400 feet above main drainage lines. The summit of the North Range is also flattish, its evelation being about 1,200 feet.

The district is drained by the Wisconsin and Baraboo rivers and their tributaries. The Wisconsin River flows from the Dells, 17 miles north of Baraboo, in a broad curve past the east end of the ranges at Portage to Prairie du Sac, where it may be said to leave the district. Baraboo River enters the district at Ableman through the North Range, in a gap known as the Upper Narrows, flows in a general easterly direction between the ranges past Baraboo, cuts back through the North Range at the Lower or Baraboo Narrows, and joins the Wisconsin River near Portage:

Devils Lake occupies the northern portion of the only gap there is through the South Range. This gap has the form of a broad open curve with a north-south course in its northern portion, an east-west course in the middle of the range, and a northwest-southeast course at the south edge of the range. About one-fourth of the length of the gap is occupied by the lake. The surface of the lake is at 960 feet A.T. which is 160 feet above the Baraboo River to the north, 200 feet above the Wisconsin River to the south, and about 500 feet lower than the flat top of the range east, west, and southeast of it (Plate I).

STRATIGRAPHY

The rocks of the district about Devils Lake include the Huronian, Cambrian, and Ordovician, each system being represented by more than one formation.

The oldest rocks of the district are granite, diorite, and rhyolite, which lie around the borders of the quartzite syncline and seem to form the basement upon which the quartzite was deposited. Next above the igneous rocks lies the Baraboo quartzite, which in turn is overlain conformably by the Seeley slate and the Freedom formation. The Baraboo, Seeley, and Freedom formations are all involved in the folded structure of the district, although the Seeley and Freedom beds do not outcrop. The total thickness of the Proterozoic formations is about 6,000 feet, the quartzite alone measuring in the North and South ranges about 5,000 feet.

There is a great unconformity between the Proterozoic and Paleozoic groups of rock. After the Proterozoic formations were deposited and folded, the region was eroded in one or more cycles until the surface in this district had a relief of at least 1,300 feet, and upon this rugged surface the Cambrian rocks were deposited.

The Cambrian system includes the Potsdam sandstone, between 600 and 700 feet thick where thickest, the Mendota limestone, 3–11 feet thick in the Devils Lake district, and the Madison sandstone, 80–90 feet thick. This is a conformable series and the strata are essentially horizontal. Away from the ranges the top of the Madison sandstone is about 1,020 A.T., but the standsone laps up on the ranges to altitudes of 1,200 feet or higher.

Only the Prairie du Chien and St. Peter formations of the Ordovician system now appear in the vicinity of Devils Lake, although it is nearly certain that younger formations were deposited here originally and have been eroded away.

The Prairie du Chien formation overlies the Madison sandstone conformably, but outcrops in only a few localities within the boundaries of the Devils Lake district. It is hard, cherty dolomite. Its average thickness in the Mississippi Valley is about 200 feet, although in the immediate vicinity of Devils Lake its greatest thickness is 20 feet.

An unconformity is known to exist between the St. Peter and Prairie du Chien formations in Iowa, Illinois, Wisconsin, and Minnesota, and is well represented in the Devils Lake district. If the total thickness of 200 feet of Prairie du Chien dolomite was

deposited here, all but 20 feet was eroded away a mile southeast of the Baraboo Narrows, before the deposition of the St. Peter sandstone. At Gibraltar Rock, 8 miles southeast of Devils Lake, there is a thickness of 73 feet of Prairie du Chien dolomite between the St. Peter and Madison sandstones on the southeast slope of the hill and none at all on the southwest slope, the St. Peter sandstone lying directly on the Madison sandstone on the southwest side. It is believed that the Prairie du Chien dolomite was entirely removed in other places also, before the St. Peter sandstone was deposited, as on the hill a mile south of the Pewits Nest (see Plate II). The St. Peter formation is a massive, medium-grained, quartz formation so similar to the Madison that the two cannot be separated on lithologic grounds. The St. Peter sandstone is thought by some geologists to be of eolian origin, but most of it at least seems to be marine. In thickness the St. Peter varies from a few feet to more than 200 feet within the district. The variation is due to the erosion surface on which it lies, and to post-St. Peter erosion of its surface.

Platteville limestone, Galena dolomite, and Maquoketa shale are all found at Blue Mounds, 26 miles to the south of Devils Lake, and its seems certain that these formations once covered the Devils Lake district. If so, they were eroded away in some late Paleozoic, Mesozoic, or Cenozoic erosion cycle, leaving no trace of their previous existence.

The previous existence of rocks of Silurian age in the district is proved by the finding of Niagaran fossils in a gravel deposit on the summit of the quartzite range east of Devils Lake.[1]

Aside from the late Ordovician and mid-Silurian rocks which once undoubtedly covered the region around Devils Lake, it is entirely possible, though not proved, that formations of Devonian and Carboniferous age were deposited also and were subsequently eroded away. Certain it is that thick deposits of rock were laid over the St. Peter sandstone.

Glacial drift and lacustrine deposits of late Pleistocene age lie unconformably on all the older rocks of the district (Plate II).

[1] R. D. Salisbury, *Jour. Geol.*, III, 655–67.

THE EARLIEST RECORD

The history of the depression in which Devils Lake lies goes back to pre-Cambrian times. Cambrian sandstone lies in the gap, (1) at the north end of the east bluff one mile south of the northernmost outcrop of quartzite in the South Range, 240 feet above lake-level and 270 feet below the summit plain; (2) near the foot of the west bluff, one-fourth mile north of the north end of the lake, 60 feet above lake-level and 450 feet below the tops of the bluffs; (3) at the southwest corner of the lake at "Messenger's End," where it extends from a few feet above lake-level to an altitude of 1,200 feet at the divide between Devils Lake and Skillett's Creek; and (4) forming a hill or bluff on the north wall of the gap $2\frac{1}{2}$ miles east of the lake. At the last-designated point the sandstone extends to 900 feet A.T., which is below lake-level. The presence of Cambrian sandstone at levels near that of the present lake surface, near the north end, near the southeast end, and near the center of the gap shows clearly that there was a depression or that there were depressions here before the advance of the Cambrian sea. The facts might be interpreted in one of two ways:

1. The simplest explanation lies in the assumption that after the pre-Cambrian formations were folded, the surface was eroded and reduced to a peneplain on which a river meandered, that this plain was uplifted relative to the sea, and that the district had reached late youth or early maturity in a second cycle of erosion before submergence by the Cambrian sea. Under this interpretation the original gap is a pre-Cambrian intrenched meander. The ancient peneplain may be represented by the present summit plain of the district, or it may have been entirely destroyed in subsequent periods of erosion.

2. The conditions, however, might be almost equally well explained by assuming that the district was in maturity either of its first or of some later cycle of erosion when the Cambrian sea advanced, that at that time a deep valley existed in the range with its head in the valley of Messenger's Creek and discharging eastward and southeastward, and that another stream headed somewhere north of Messenger's Creek and flowed northward into the Baraboo valley. This would not necessitate more than one cycle of

erosion in pre-Cambrian times nor would it preclude more than one cycle.

After the long series of events during the Paleozoic and subsequent history of the district, it does not seem possible to determine which of the foregoing interpretations is correct. However, some light is thrown upon the matter by consideration of the pre-Cambrian history of Wisconsin, and the principles of stream adjustment. It has been demonstrated by Weidman[1] and Martin[2] that the surface of Wisconsin was degraded to a peneplain in pre-Cambrian times, that this plain slopes south and is buried beneath Cambrian sediments at an altitude of about 300 feet in the latitude of Devils Lake, and that the quartzite ranges stood as erosion remnants on this plain. Well-records in the Baraboo valley show that the pre-Cambrian surface within the inclosure made by the ranges is as low at least in some places as 340 feet A.T. A stream must therefore have had entrance to the inclosure and a means of escape from it. A broad, continuous, stream-made gap, filled with Cambrian sediments, cuts through the North Range northwest of Baraboo, and is probably the line of entrance or exit of a large pre-Cambrian stream. The other gap, either entrance or exit, is not known unless it be the Devils Lake gap. Neither the Lower nor the Upper Narrows seems to be large enough and they have not yet been proved to be pre-Cambrian in age. It is improbable that there is a buried gap, undiscovered, either in the North or the South Range, which might have conducted the river in or out of the area between the ranges. It is unlikely also that two streams would adjust themselves as postulated in the second case above. A stream working headward into a hard, high ridge with a steep slope would hardly develop a course other than one more or less nearly straight and nearly normal to the trend of the ridge. But the stream flowing southeastward from Messenger's Creek must have had a course which was distinctly curved, had supplementary angles of 30° and 150° with the trend of the ridge, and was oblique to the dip of the rocks. On the other hand, the

[1] Samuel Weidman, *Bull. 16, Wis. Geol. and Nat. Hist. Surv.*, pp. 385–95, 592–600; *Jour. Geol.*, XI, 289–313.

[2] Lawrence Martin, *Bull. 36, Wis. Geol. and Nat. Hist. Surv.*, pp. 347–73.

freshness and apparent youth of Devils Lake gap, and its size, harmonious with the dimensions of the Upper and Lower Narrows, suggest that these three gaps were cut at the same time and during some post-Silurian period. And yet Devils Lake gap may have carried a large river in pre-Cambrian times and the gap may have been reoccupied at a later time when the two Baraboo narrows were cut.

Whether the pre-Cambrian Devils Lake gap was cut by a single intrenched meandering stream, or by two streams with a col between them, the depression must have been a deep one. The rim of the canyon is today represented by the 1,470-foot summit plain, and the pre-Cambrian rim may have been higher than this. Cambrian sandstone in the gap is known as low as 900 feet A.T. The depression must therefore have been at least 570 feet deep in pre-Cambrian times. Certainly if the gap was cut by the same stream which reduced the inclosure between the ranges to 340 feet A.T., and probably if it was cut by two streams tributary to main drainage, the bottom of the gap at the end of pre-Cambrian times was not much higher than 340 feet A.T. The pre-Cambrian gap was then probably not far from 1,100 feet deep. The whole district at this time is known to have had a relief of 1,200 or 1,300 feet.

PALEOZOIC HISTORY

The Paleozoic, marine, sedimentary rocks of the district record the second important step in the known history of the district.

Upper Cambrian sandstone is found on the ranges to an altitude of 1,200 feet A.T. and probably exists at slightly higher levels. On Wood's Quarry Hill, 3 miles northwest of the lake, rounded pebbles of quartzite are found in the uppermost beds of the Madison formation where it is overlain conformably by Ordovician dolomite, giving evidence that quartzite was exposed on near-by land up until the very end of the Cambrian period. In the light of these facts, it is believed that the South Range was an island in the Cambrian sea, and that the Devils Lake gap was not filled to a higher level than 1,020 feet, although the sea seems to have reached at least to 1,200 feet.

But deposition did not end with the Cambrian period. The Prairie du Chien and St. Peter formations, or their time equivalents, must have been deposited in the gap. It is clear that the sediments of the Prairie du Chien stage did not fill the gap, for the base of this formation has an elevation of 1,020 feet in the vicinity, and it would require a thickness of 500 feet to have filled the gap. As the formation is nowhere known to be so thick, it is probable that a sag existed at the site of the present gap, when the Prairie du Chien sea had withdrawn, and it is possible that the gap was again occupied by running water and partly re-excavated before the deposition of the St. Peter sandstone. As the St. Peter sandstone is not found much above 1,300 feet in the district, it seems clear that the gap was not entirely filled with this deposit.

Although no traces of the Platteville, Galena, and Maquoketa formations are found in Devils Lake gap or in its immediate vicinity, it seems clear that these formations, or their time equivalents, were deposited in the gap, filled it, and buried it, for if the dip of these formations be projected northward from their existing altitude at Blue Mounds and other points to the south, the bottom of the Maquoketa formation would lie 200 or 300 feet above the summit plain on the South Range. Gravels containing Niagaran fossils are found to the very top of the range on the flat summit plain east of the lake, showing that this formation added its thickness to the sediments which buried the filled gap and the ranges.

If still younger Paleozoic formations were deposited over the district and over the filled gap, they have left no record. So far as the records go, the Paleozoic sea retreated finally at some date after the Niagaran epoch. These seas probably left the district essentially flat, with the rough surface of the quartzite buried beneath thick Paleozoic sediments. At this time there was no Devils Lake gap as a topographic feature, but there was a previously existing gap, filled with sediments and buried by formations which also covered the ranges deeply.

POST-PALEOZOIC—PRE-GLACIAL HISTORY

The record of the history of the gap following the final withdrawal of the Paleozoic seas and antedating the advance of the

Wisconsin glacier is to be read only from the study of the topography and surficial deposits of this and surrounding districts.

The flat summit areas at various places on the South Range at altitudes between 1,400 and 1,480 feet, lying across the beveled edges of the quartzite beds, can be interpreted only as an ancient plain of degradation now almost destroyed by streams working in a later erosion cycle. The peneplain might be considered to be of pre-Cambrian age but for the fact that there are stream gravels on its surface which are composed of Paleozoic rocks, and contain fragments in which are imbedded Niagaran fossils. Associated with the gravel there are numbers of potholes which are not filled by Paleozoic sediments and which probably are of post-Niagaran age. The idea that the flat is a remnant of the old pre-Cambrian plain buried by Paleozoic formations, resurrected by later erosion, and becoming again the site of deposition as a part of the later peneplain, is perhaps tenable, although hardly probable, for the extension of this plain has now been traced west into Iowa and south into Illinois, in both of which states it cuts across the beveled edges of the Potsdam, Prairie du Chien, St. Peter, Platteville, Galena, and Niagara formations in order.

It is not to be understood that this erosion surface had reached a final stage of degradation and was perfectly flat. It is made clear by a study of the Devils Lake district, as of other districts where the plain is known, that it had considerable relief. West of Devils Lake the surface of the plain is 1,400 feet A.T., which seems to be the altitude of the portion which was brought to grade. East of the lake the gravels lie on a flattish surface at 1,470 feet, and quartzite at Sauk Point reaches an altitude of about 1,600 feet. Before this surface was dissected, it had a relief of 200 feet in the Devils Lake district, and the gravel occupies a position between the lowest and highest portions of the surface. The gravels probably were not brought from a distance by a long and large stream at grade, but were more likely to have been deposited by a stream tributary to main drainage, the tributary having enough velocity to carry gravel and to cut potholes. The gravels include no material which could not have been derived from local formations. On the other hand, the relief of the surface must have been much

less than that of the present surface, and Devils Lake gap could not have existed at the time.

The exact age of this erosion surface is still an open question. Where the plain and the gravel associated with it are known outside this district, they have been assigned by different writers to different ages. Winchell[1] long ago correlated these gravels in Minnesota tentatively with the Cretaceous, and following his lead Bain,[2] Calvin,[3] Grant and Burchard,[4] Hershey,[5] and others have considered the plain to have been formed chiefly during the Cretaceous period. This correlation is, however, somewhat doubtful, for the reason that it has never been proved that the gravel on the plain in Minnesota is of Cretaceous age. It seems to lie on the Cretaceous, a relationship which tends to show that the plain cuts across the edges of the eroded Cretaceous rocks and is therefore post-Cretaceous in age, just as the fact that it cuts across the Paleozoic sediments proves that it is younger than those sediments. Most likely the plain is of Tertiary age. The evidence of this has been presented by Salisbury[6] in an article in which he suggests the correlation of these patches of gravel with the Lafayette formation farther south.

It is at least clear that the Devils Lake gap remained filled with Paleozoic sediments while this plain was being formed, and that the time involved was long.

There are strong suggestions of a second flattish erosion surface with remnants at about 1,200 feet. Representatives of this surface may be found (1) cutting across the beveled edges of the vertical quartzite beds of the North Range at the Upper Narrows, (2) at the Lower Narrows, (3) 2 miles northeast of Denzer, (4) on the summit of Old Flat Top, 1 mile southeast of the Lower Narrows, (5) on the top of Gibraltar Rock, 1½ miles west of Okee, and (6) forming saddles or low divides in the South Range, as on the

[1] N. H. Winchell, *Geol. and Nat. Hist. Surv. Minn.*, I, 309–31, 353–56.

[2] H. F. Bain, *Bull. U.S. Geol. Surv., No. 294*, pp. 11–16.

[3] Samuel Calvin, *Iowa Geol. Surv.*, IV, 43.

[4] Grant and Burchard, Lancaster Mineral Point Folio, *U.S. Geol. Surv.*, p. 2.

[5] O. H. Hershey, *Am. Geol.*, XX, 246–59.

[6] R. D. Salisbury, *Jour. Geol.*, III, 655–67.

divides between the North Fork of Messenger's Creek and Skillett's Creek, between the South Fork of Messenger's Creek and an unnamed south-flowing stream, between Pine Creek and Otter Creek, etc. Because the remnants of this plain within the district cut across the quartzite beds and lie on St. Peter sandstone, and because most of the streams of the district find their sources on the plain, the remnants are believed to represent parts of a plain of erosion developed at this level, but now mostly dissected. This interpretation is greatly strengthened by the finding of a similar plain, bearing the same relation to the older plain, and cutting across the edges of eroded formations, at many places outside the district under consideration, as, for instance, in the Richland Center quadrangle, in the Sparta quadrangle, in the Lancaster and Mineral Point quadrangles, in the eastern portions of the Waukon and Elkader quadrangles in Wisconsin, in Jo Daviess County, Illinois, in Allamakee, Clayton, and Dubuque counties in Iowa, and at various places in southeastern Minnesota.[1]

If this plain is correctly interpreted, it records the following steps in the history of the district in general and of Devils Lake gap in particular. After the 1,400–1,480 foot plain was developed, the district was uplifted relative to the sea-level of that time to an amount of approximately 200 feet, the streams were rejuvenated, and reached grade again at levels 200 feet lower than the first plain.

It was during this cycle of erosion that Devils Lake gap was re-excavated and the Upper and Lower Narrows were formed, or re-formed if they are of pre-Cambrian age. In the formation of these post-Paleozoic gaps problems of stream adjustment are involved. Martin[2] expresses disbelief in the two peneplains in this part of the country, considers that all post-Niagaran and pre-Wisconsin erosion took place in a single cycle, and believes that the Devils Lake gap, and the two Baraboo gaps in the North Range,

[1] O. H. Hershey, *Am. Geol.*, XX, 246–59; U. B. Hughes, *Proc. Iowa Acad. Sci.*, XXIII, 125–32; W. D. Shipton, Master's thesis, University of Iowa Library; U. S. Grant and E. F. Burchard, Lancaster Mineral Point Folio, *U.S. Geol. Surv.*, p. 2; A. C. Trowbridge and E. W. Shaw, *Bull. No. 26, Ill. Geol. Surv.*, pp. 136–44; A. C. Trowbridge, *Bull. Geol. Soc. Am.*, XXVI, 76.

[2] Lawrence Martin, *Bull. No. 36, Wis. Geol. and Nat. Hist. Surv.*, pp. 63–70 and 177.

were made by the Wisconsin and Baraboo rivers developing their courses on the surface of the Paleozoic rocks, cutting down through these rocks and becoming superimposed on the ranges, and holding their courses. In the case of Devils Lake gap, at least, this hypothesis seems to involve too nice a coincidence. Whether the pre-Cambrian gap was continuous or made up of two valleys with a col between, Martin's idea would mean that a crooked stream starting on a surface 1,200 feet or more above final grade, cuts down more than 300 feet, then develops a flat surface and deposits fine gravel without ceasing to cut, is superimposed on quartzite in a course exactly coinciding with a peculiar pre-existing filled and buried crooked valley, and then cuts on downward for 900 feet without interruption.

It seems more likely to the writer that the explanation of the reoccupation of the gap by a stream is to be found in the application of the principle of stream adjustment on non-resistant rocks during a cycle of erosion which went nearly to completion. On the 1,400–1,480 foot surface, the streams flowed here on quartzite and there on sandstone. With the uplift of the surface, these streams began to intrench themselves and new tributaries were formed. The larger streams reached grade after cutting 200 feet or so. For most of the streams this downward cutting was through quartzite. The stream which adjusted on the non-resistant sandstone in the gap cut more rapidly than the others, obtaining an advantage in this way; it became a pirate and gradually captured many of the other streams. That there were other streams during this cycle and that they did intrench themselves before being captured is proved by the fact that there are passes or cols across the range at altitudes a little above 1,200 feet, as, for instance, where the West Sauk road crosses the range between the heads of Skillett's Creek and Otter Creek.

At any rate, it was during this cycle of erosion that the Wisconsin or its pre-Glacial ancestor came to flow southward and westward over the present site of the Lower Narrows, up the present course of the Baraboo valley and southward through the shallow Devils Lake gap, and the Baraboo River entered the inclosure between the quartzite ridges through the Upper Narrows, and

joined the Wisconsin at about its point of entrance to Devils Lake gap. The Upper and Lower Narrows may have been formed for the first time by superimposition during the formation of the 1,200-foot plain, or possibly by adjustment of the streams on sandstone, provided they had been made and filled with sandstone.

The age of this lower plain and therefore the date of re-excavation of Devils Lake gap are no more proved than is the age of the upper erosional surface. Those who hold that the upper plain is Cretaceous assign a Tertiary age to the younger plain, and those who believe the upper plain to be Tertiary in age naturally assume that the lower plain was formed at the end of the Tertiary period or early in the Pleistocene. There is some evidence in northeastern Iowa that this plain was intact when the oldest glacial drift was deposited, but this also must be considered to be an open question until more of the field data have been published. At least it is clear that the present Devils Lake gap had its beginnings either in late Tertiary or in early Pleistocene times, which for present purposes is perhaps close enough.

Long before the monadnocks had been removed from this lower plain—that is, before the second cycle of erosion had reached completion—there was another uplift of the land relative to the then existing seas, and the streams were again rejuvenated. This uplift was much greater than the previous one, for the valleys cut during this third cycle of erosion are much deeper than any which were cut during the second cycle. At this time, too, the main part of the present Devils Lake gap was cut. The bottom of the gap at the beginning of this erosion cycle could not have been lower than 1,200 feet A.T. and the tops of the bluffs were no higher than 1,470 feet; that is, the maximum depth of the valley up to the beginning of the last erosion cycle preceding the deposition of the glacial drift was 270 feet. The maximum depth of the valley at the end of this cycle could be determined, if it were possible to get the altitude of bedrock underlying the glacial deposits in the middle of the gap, a bit of information which unfortunately is not available. The deepest boring into the glacial material within the gap was made by Gustaffson and Prader in 1914 at a point near the middle of the gap at the north end of Devils Lake, only a few feet above

lake-level. The altitude of the well-site is about 965 feet. This well penetrates 283 feet of glacial material without striking rock; therefore the bottom of the pre-Glacial gap must be somewhere below 682 feet, and the pre-Glacial gap at this point must have been at least 788 feet deep, at least 500 feet deeper than it was at the end of the second erosion cycle, and at least 283 feet deeper than it is today. The maximum depth of this gap might be known if the altitude of the lowest sub-drift bedrock in the Baraboo valley between the ranges or in the Wisconsin valley south of the South Range could be obtained, assuming that a stream flowed from the Baraboo valley through the gap to the Wisconsin valley to the south. The lowest bedrock surface obtainable in the Baraboo valley east of Baraboo is at 570 feet. Assuming that the bedrock in the Devils Lake gap is as low, the pre-Glacial gap was at least 900 feet deep. It cannot be ascertained whether the pre-Cambrian gap was deeper than this or not so deep, for it cannot be determined whether there are Paleozoic sediments below the bottom of the present gap, nor whether the tops of the ranges were higher then than now. If it be true that the bottom of the pre-Cambrian gap lies at or near 340 feet, the pre-Cambrian gap was probably something like 200 feet deeper than the pre-Glacial gap.

THE GLACIAL LAKE

So far as ascertained, no glacier prior to the Wisconsin glacier affected the Devils Lake gap. There have been some suggestions of pre-Wisconsin drift in the vicinity,[1] but these evidences have proved to be negative. It seems likely, however, that the Illinoian glacier advanced almost to this district; but if it played any part in the history of the lake or its basin, its effects are not now visible within the district.

As has been brought out by Salisbury and Atwood,[2] the Wisconsin glacier formed Devils Lake and had a controlling influence in its early history. As the ice moved into the district from the northeast, it was divided by the ranges, one lobe advancing down the

[1] Samuel Weidman, *Bull. No. 13, Wis. Geol. and Nat. Hist. Surv.*, pp. 99–102.

[2] R. D. Salisbury and W. W. Atwood, *Bull. No. 5, Wis. Geol. and Nat. Hist. Surv.*, pp. 132–33.

old valley of the Wisconsin from the Lower Narrows to the north end of Devils Lake gap, where its edge became stationary and deposited a terminal moraine, the other lobe coming in south of the South Range and advancing up the valley of the pre-Glacial Wisconsin to deposit a marginal ridge across the gap east of its major bend (Plate II). This left the north-south portion of the gap and a part of the east-west portion confined between the two edges of the ice, and in the basin so made Devils Lake was formed. Connecting the ends of the two lobes, the edge of the ice reached its limits of advance in an irregular line crossing the South Range from the north edge of Devils Lake eastward to Sauk Point, and thence southwestward to the gap east of Kirkland (Plate II).

After its formation the lake had an interesting history during the occupancy of the ice.

Sources of supply.—When the lake was first formed, as outlined above, there were at least four separate sources of water supply: (1) The edge of the glacier blocked either end of the lake basin. There the ice melted and furnished water for the basin. Study of the terminal moraine from the north end of the lake around by Sauk Point and southwest to the gap east of Kirkland leads to the conclusion that the water resulting from melting along this whole stretch of ice front must have flowed into Devils Lake basin. (2) The bottom of the basin was below ground-water surface, as evidenced by the fact that it had been occupied by a permanent stream up to the time when this stream was blocked by the ice, and ground water was a source of supply. From the inception of the lake until its bottom was built up above ground-water surface by fluvio-glacial deposition, if this stage was ever reached, some of the lake water may have come from under ground. (3) The lake must have had inlets resulting from precipitation within the borders of the lake basin. For instance, Messenger's Creek with its north and south forks must have flowed into the southwest corner of the lake as it does today, and the stream which flows west and north past the northeast corner of the lake, being blocked to the north by the ice, must have contributed its waters to the lake. (4) There was doubtless direct precipitation upon the surface of the lake. Of these four sources of supply, the first men-

tioned is conceived to be most important, and needs more complete description.

From the extreme east end of the east loop of the terminal moraine at the west foot of Sauk Point, the land slopes south from the north limb of the moraine, north from the south limb, and west from the junction of the two limbs. The water formed by melting at the edge of the ice must therefore have concentrated in the depression between the two limbs of the moraine and must have

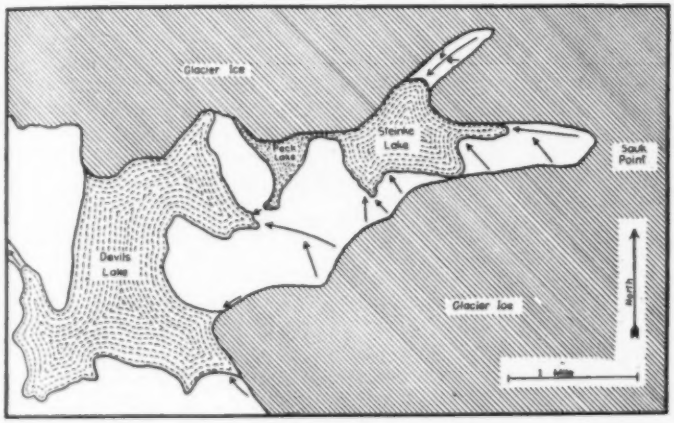


FIG. 1.—Sketch map showing Devils Lake and its drainage basin during the occupancy of the ice.

flowed westward into what has been called the Steinke Lake by Salisbury and Atwood[1] (see Fig. 1). The same general conditions existed in the minor loop north of the Steinke Lake, and the waters from this loop must have mingled with those from Sauk Point in the Steinke Lake.

The Steinke Lake was a body of water about $\frac{3}{4}$ mile long east and west and $\frac{1}{4}$ mile broad north and south, held in by a low ridge of quartzite on the west, the north limb of the ice edge on the north, the westward slope of the land from Sauk Point on the east, and the northward slope of the South Range and the south limb of the

[1] R. D. Salisbury and W. W. Atwood, *Bull. No. 5, Wis. Geol. and Nat. Hist. Surv.*, pp. 120, 133–34, Pl. XXXVII.

ice edge on the south. Short arms or bays projected east toward Sauk Point and north into the narrow loop of the ice edge. As discovered by Salisbury and Atwood, the lowest point in the basin of this extinct lake during the occupancy of the ice, and hence the head of the outlet of the lake, was at the extreme northwest corner of the lake a few rods across the Merrimac Road west of the home of Julius Steinke. The bottom of this outlet is at approximately 1,250 feet A.T., and as the outlet is broad and shallow, it may be assumed that the level of the lake was little if any above 1,260. The water from this lake flowed westward along the front of the ice toward Devils Lake.

The materials now occupying the site of this extinct lake are lacustrine silts, sands, and gravels, finely divided near the middle and coarser around the borders, and coarser at the surface than in the bottoms of deep cuts or borings. The maximum depth of the original lake is not known, but a well on the north side of the flat at the house next west of the schoolhouse, whose site is at 1,260 on lacustrine material, penetrates 202 feet of what appears to be lacustrine material, without reaching rock. This indicates that the original lake was at least 200 feet deep, and that the 200 feet of debris deposited in it was sufficient to fill the lake basin by the time of the retreat of the ice.

From the Steinke Lake the water drained westward into a small pocket or basin having a flat bottom. In late years this little plain has been known locally as the Peck flat. It is an area of perhaps 80 acres, bordering the terminal moraine on the north and sloping gently and getting narrower to the south. On the west, east, and south there are high hills of quartzite, but there is a break in the rim of the basin at its southwest corner, through which drainage is free to flow south and west to the north end of Devils Lake. The width and depth of this valley, the hardness of the quartzite which forms its walls and bottom, and the small size and intermittent character of the stream which drains it, when compared with the post-Glacial valleys of Skillett's Creek and the Wisconsin River, show that this outlet to Peck flat is pre-Glacial. Yet when all available authentic well-records are considered, it is clear that glacial waters could not have flowed at first through this outlet

depression unobstructed. The accompanying table gives the altitudes of well-sites and rock outcrops, depths to sandstone, altitudes of bedrock, etc., for points located in Fig. 2.

TABLE OF WELLS AND OUTCROPS IN THE PECK BASIN

Wells and Outcrops	Altitude of Sight (Feet)	Depth to Sandstone (Feet)	Elevation of Sandstone Surface (Feet)	Depth to Quartzite (Feet)	Elevation of Quartzite Surface (Feet)
Johnson well	1,280	113	1,167	?	?
Peck drilled well	1,225	38	1,187	?	?
Peck dug well	1,220	26+	1,194−	?	?
Iron drill hole	1,210	18	1,192	297+	913−
Marquid well	1,215	6	1,209	121+	1,094−
Steinke sandstone outcrop	1,205	0	1,205	?	?
Steinke quartzite outcrop	1,180	.....	.....	0	1,180
Steinke well	1,218	6	1,212	155	1,063

From this table and from Fig. 3, it is made clear that the pre-Cambrian surface of this section, as of all portions of the district, was very irregular, and that the post-Paleozoic and pre-Glacial surface sloped north and west from opposite sides of a divide located somewhere near the south end of the present flat.

It is clear that the ice advancing from the north blocked drainage in that direction and melting, furnished water which joined with the discharge from Steinke Lake to make a small lake in the Peck basin. The waters of this lake rose rapidly to the level of the divide at the south end of the basin and overflowed westward into Devils Lake. Peck Lake, shallow from the first, was gradually filled until the lowest point on its bottom was as high as the outlet, and the lake ceased to exist. The filling of the lake must have been accomplished before the retreat of the glacier, for fluvio-glacial material was deposited over the lacustro-glacial material. The Peck dug well (see Fig. 2) penetrates 8 feet of coarse gravel and below that 18 feet of sand. The gravel is fluvio-glacial and the sand below lacustro-glacial. The top of the sand is at 1,212 feet A.T., and this is probably the approximate altitude of the pre-Glacial divide.

From the foregoing it is apparent that all the water from the edge of the glacier in its great complex loop east of Devils Lake flowed into Devils Lake during the occupancy of the ice (see Fig. 1).

The Size of Glacial Devils Lake.—After description of the sources of supply for the basin of Devils Lake during the occupancy of the

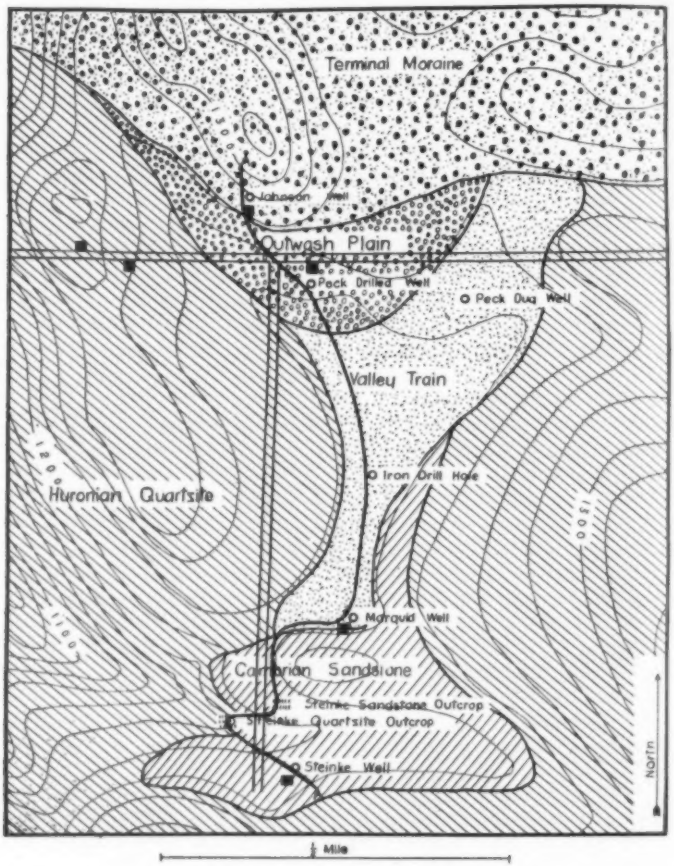


FIG. 2.—A geologic and topographic map of the Peck basin. The locations of wells and outcrops involved in the accompanying table are given, also the line of the section *AA*, shown in Fig. 3.

ice, it is evident that the glacial lake must have been larger than now after most of these sources have been cut off. Indeed, there

is a question as to whether the basin of Devils Lake was large enough to confine all this water. If it be assumed that the amount of water supplied to the basin by ground water was balanced by loss due to seepage into the débris at either end of the lake, and that the precipitation on the surface of the lake and on the lakeward

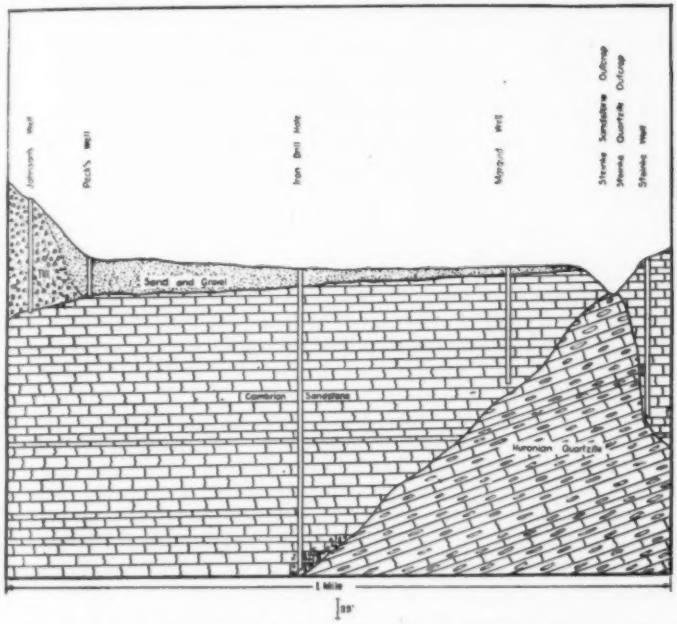


FIG. 3.—Section along line *AA*, Fig. 2, showing surficial and underground conditions in the Peck basin.

slopes was balanced by evaporation, the glacial water is still unaccounted for.

Careful measurement of the terminal moraine from the northwest edge of the Devils Lake basin, through all its curves to the crest of the Devils Nose southeast of the lake, shows that water drained into Devils Lake from 11.6 miles of ice edge. To get some conception of the amount of water which this front of ice contributed, let us suppose that the ice edge tributary to the lake had

an average thickness of 100 feet (probably less than the actual thickness) for the first mile back from its edge. To estimate the total annual water supply from the ice, it is necessary to make reasonable supposition as to the amount of annual melting measured in a horizontal line normal to the front of the ice. The ice front may be considered to have been essentially stationary, and the amount of ice melted can be measured by the rate of glacial motion in the marginal portions of the ice. Chamberlin and Salisbury[1] estimate that the ice in the Greenland glacier moves something less than a foot a week near its edge. Suppose that the glacier which affected Devils Lake moved 6 inches a week or 26 feet a year. If, then, it be assumed that a volume of ice 11.6 miles long measured along the edge of the glacier, 100 feet thick measured vertically, and 26 feet wide measured normally to the ice front, melted each year and ran into Devils Lake, there would be an annual total of about 1½ *billion* cubic feet. The decreased volume due to change from ice to water may be neglected in a computation where there are so many assumptions and where all figures have been reduced to a minimum for safety.

To estimate the capacity of the basin of Devils Lake during the occupancy of the ice, it is necessary to have its length, width, and depth. Measured from moraine to moraine around the curve of the gap, the basin is almost exactly 2 miles long. The average width from end to end and from lake level to lowest point in the rim of the basin is approximately ½ mile. The depth of the glacial lake may be found by subtracting the altitude of the present lake bottom from the altitude of the lowest point in the rim of the basin, neglecting the glacial débris below the bottom of the lake, which would have displaced the water as it was deposited. Computed in this way, the maximum depth of the glacial lake was 270 feet. Multiplying the depth, width, and length, the capacity of the glacial basin was about 7½ *billion* cubic feet.

According to these figures the water from the glacier would have filled the basin of Devils Lake to overflowing in about five years. If the rate of advance of the ice was greater than assumed above

[1] T. C. Chamberlin and R. D. Salisbury, *Geology*, I, 261.

or if the ice was thicker, and both postulates are reasonable, the time required to fill the basin would have been less.

The foregoing figures may be roughly checked by an estimate of the amount of material deposited by the glacial waters. The 6 miles of ice edge which drained into Steinke Lake furnished water enough to deposit over $2\frac{1}{2}$ *billion* cubic feet *of débris;* in the Peck basin water running from $\frac{1}{2}$ mile of ice front deposited at least 142 million cubic feet *of débris;* it therefore seems safe to assume that over 11 miles of ice edge furnished over $7\frac{1}{2}$ billion cubic feet *of water*. The Devils Lake gap between the two moraine dams contains over 2 billion cubic feet of débris (10,000 feet in length × 1,000 feet in width × 283 feet in depth) and most of this must have come in the water from the two short stretches of glacier to the north and southeast, the water from the Steinke and Peck basins doubtless having been essentially clear.

It is not necessary to go farther to warrant the assumption that Devils Lake must have risen during the glacial epoch until it reached an outlet. On the edges of the basin there are only four low points: (1) over the terminal moraine east of the south end of the lake, (2) over or around the west edge of the moraine north of the lake, (3) at the head of the south fork of Messenger's Creek, (4) at the head of the north fork of Messenger's Creek. If the openings to the east and north be considered to have been blocked by the ice, as they doubtless were during the glacial occupancy, the lowest outlet available was between the head of the north fork of Messenger's Creek and the head of a valley tributary to the east fork of Skillett's Creek, where the altitude is between 1,180 and 1,200 feet A.T.

Salisbury and Atwood[1] found evidence that the glacial lake stood 90 feet higher than the present lake, by finding erratic, iceberg-floated bowlders in the talus on the west bluff of the lake at altitudes of 1,050 feet. Theorizing that the lake must have stood even higher than this, that it must have had an outlet, and that icebergs would float toward, and strand in, such an outlet, the writer has made

[1] R. D. Salisbury and W. W. Atwood, *Bull. No. 5, Wis. Geol. and Nat. Hist. Surv.*, p. 133.

careful search for erratic bowlders in the valleys of the north and south forks of Messenger's Creek. An hour's search revealed 103 such bowlders in the valley of the north fork, and an equal time in the valley of the south fork failed to discover one. The highest igneous rock bowlder in the north fork is at 1,162 feet, 202 feet above present lake-level, and only 28 feet lower than the divide across which the lake-water must have drained. Glacial cobbles occur within 16 vertical feet of the divide, and one diabase cobble was found on the west slope of the divide in the drainage of Skillett's Creek.

It is concluded, therefore, that during the Wisconsin epoch the waters of Devils Lake stood against the glacier at the north end, formed a bay up the valley to the northeast about as far as the north-south road in the Peck flat, reached to about the level of Elephant's Rock on the east bluff, stood against the ice at the southeast extremity of the basin, extended to within a short distance of the head of the south fork of Messenger's Creek, and spilled over the divide at the head of the north fork of Messenger's Creek, as shown in Fig. 1 and Fig. 4. Through this outlet the water flowed west into a larger lake, known as the Upper Baraboo Lake, now extinct.

THE POST-GLACIAL LAKE

As the edge of the glacier receded during the closing stages of the Wisconsin glacial epoch, the high level of the lake and its westward-flowing outlet may have been maintained for a time, but when a connection was established between Devils Lake and a lake which came into existence in the Baraboo valley, and whose surface stood at a lower level, the waters of Devils Lake were lowered to the lowest point in the morainic dams. The lowest point on the surface of either moraine was a little east of the middle of the gap at the north end of the lake, along the site of the railroad and wagon road from the lake to Baraboo. The original level of this outlet is not known, because it has now been cut almost to lake-level, but the edges of the outlet gap on the surface of the moraine at either side are at about 1,020 feet, or 60 feet above present lake-level. This is approximately the level of the surface of Devils Lake after the retreat of the ice, and before the outlet had been lowered appreciably.

From the 1,020 foot level (60 feet above the present lake) the lake surface probably was brought down rapidly by the lowering of its outlet. The stream flowing north across the moraine cut its

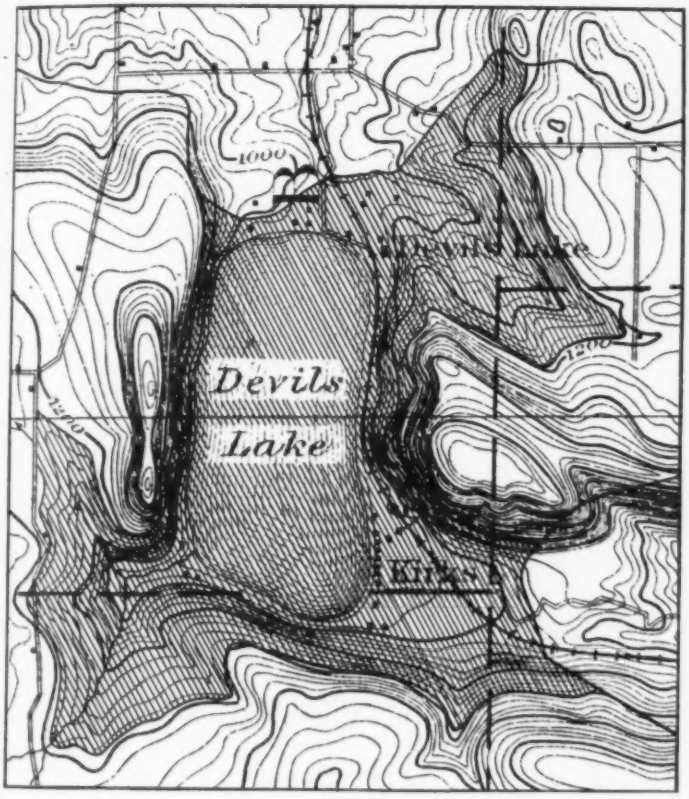


FIG. 4.—A map showing the shape and size of Devils Lake during the occupancy of the ice. The shaded area shows the lake surface. The arrow near the left margin designates the outlet. Scale: 1¾ inches equal 1 mile.

way downward in the glacial till, removing the fine material, but leaving the bowlders on its bed, lowering the lake surface from 1,020 to about 970 feet.

The lake surface apparently stood at this level (970 feet) for a time, perhaps because the outlet had made a resistant bed for itself by the accumulation of bowlders on its bottom. The evidence of this stage is a well-defined beach or barrier ridge of sand across the north end of the lake, whose crest is 8–10 feet above the lake and which confines a low, peaty area between it and the moraine. This low area back of the ridge was clearly once a lagoon. The ridge has been so strengthened artificially that it is impossible to tell whether or not it was originally broken at the old outlet, but water which could reach the top of the ridge could today flow north through the old outlet to the Baraboo River.

During this second stage of the lake it is believed still to have been receiving water from the Peck and Steinke basins (though the lakes of these names were extinct) and from a later post-Glacial lake northeast of the Steinke flat, which has become known locally as Shubring Lake. Shubring Lake occupied what is now a flat area, 1 mile by $\frac{1}{3}$ mile in extent, 4 miles northeast of Devils Lake, and just across the terminal moraine from the Steinke flat in the area of ground moraine. The Shubring flat is bordered on the north, west, and south by the inner edge of the terminal moraine and on the east by a drift-covered hill of quartzite. The slopes toward the flat are almost covered in a narrow belt parallel with the edges of the flat by thousands of bowlders which almost form a wall around the old lake bottom and which were concentrated on the shores of the shallow lake by "ice push." This lake was formed as the edge of the ice retreated, leaving an inclosed basin. During the first stages of recession of the ice, the lake received glacial waters, and after the ice had left the confines of the basin precipitation formed the source of supply. The line of outlet of the lake is plainly seen as a flat-bottomed, bowlder-strewn, linear depression interrupting the course of the terminal moraine from the southwest end of the Shubring flat to the Steinke flat south of it, and now used by Mr. Shubring as a roadway across the terminal moraine. The bottom of the valley which was the site of the outlet and the bowlder wall around the lake flat are at the same altitude (hand-level measurement), and not more than 2 feet above the level of the flat. The original depth of the lake is unknown, no records of the depth of the lacustrine fill being available.

It is clear from a study of the post-Glacial drainage conditions east of Devils Lake that the water from Shubring Lake and the Steinke Basin continued to drain into Devils Lake by way of Peck flat for a time at least after the withdrawal of the edge of the ice. These conditions must have persisted until a tributary of the Baraboo River had time to work headward up through the ground moraine on the slope of the South Range and through the terminal

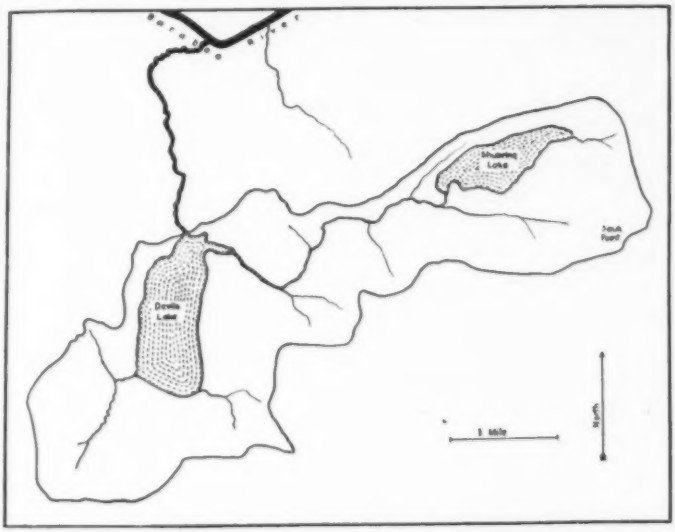


FIG. 5.—Sketch map showing the conditions of drainage around Devils Lake during the first and second stages in the post-Glacial history of the lake. The endless line marks the boundaries of the drainage basin of the lake during these stages.

moraine, to tap the Shubring and Steinke basins and divert their drainage to the north, inaugurating present conditions. The establishment of present drainage would require at least a time commensurate with the time involved in the lowering of the outlet of Devils Lake to the 970-foot level.

So long as Devils Lake had an outlet to the north, that is, until the 970-foot stage was reached, the boundaries of its basin must have been somewhat as shown in Fig. 5.

There remains but one step in the pre-human history of Devils Lake. Its outlet to the north has been abandoned. The reasons for the sinking of the surface of the lake below the level of the outlet may be several. With the gradual establishment of drainage in the ground moraine of the Baraboo valley, a tributary to the Baraboo River worked its way headward up the drift-covered slope of the South Range and through the terminal moraine into the northern

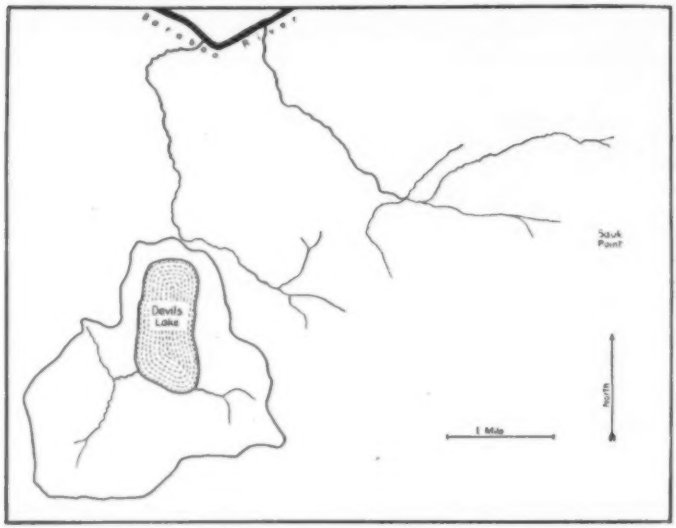


FIG. 6.—Sketch map showing the conditions of drainage around Devils Lake after the diversion of water from the Steinke and Shubring basins and the abandonment of the northward outlet. The endless line marks the boundaries of the drainage basin of Devils Lake.

portion of the Steinke flat, diverting the drainage from the east and northeast, which up to this time had gone to Devils Lake, to Baraboo River. Working rapidly in the non-resistant material of the high Steinke surface, the stream developed a tributary which worked back through the terminal moraine, tapping the Shubring basin west of its original outlet. This diversion of drainage resulted in a considerable decrease in the supply of water for Devils Lake (compare Figs. 5 and 6) and doubtless helped to

cause the lake surface to sink below the level of its outlet. Conceivably also the advance of the post-Glacial epoch was attended by increasing temperature and increasing evaporation and by decreasing precipitation, so that more water was lost by evaporation than was supplied by precipitation. And perhaps the time came when underground lines of drainage were established in the gravel and sand of the drift, through which enough water was carried from the lake to cause its surface to subside. Doubtless all these factors and possibly others contributed to the lowering of the surface of the lake and the abandonment of its outlet.

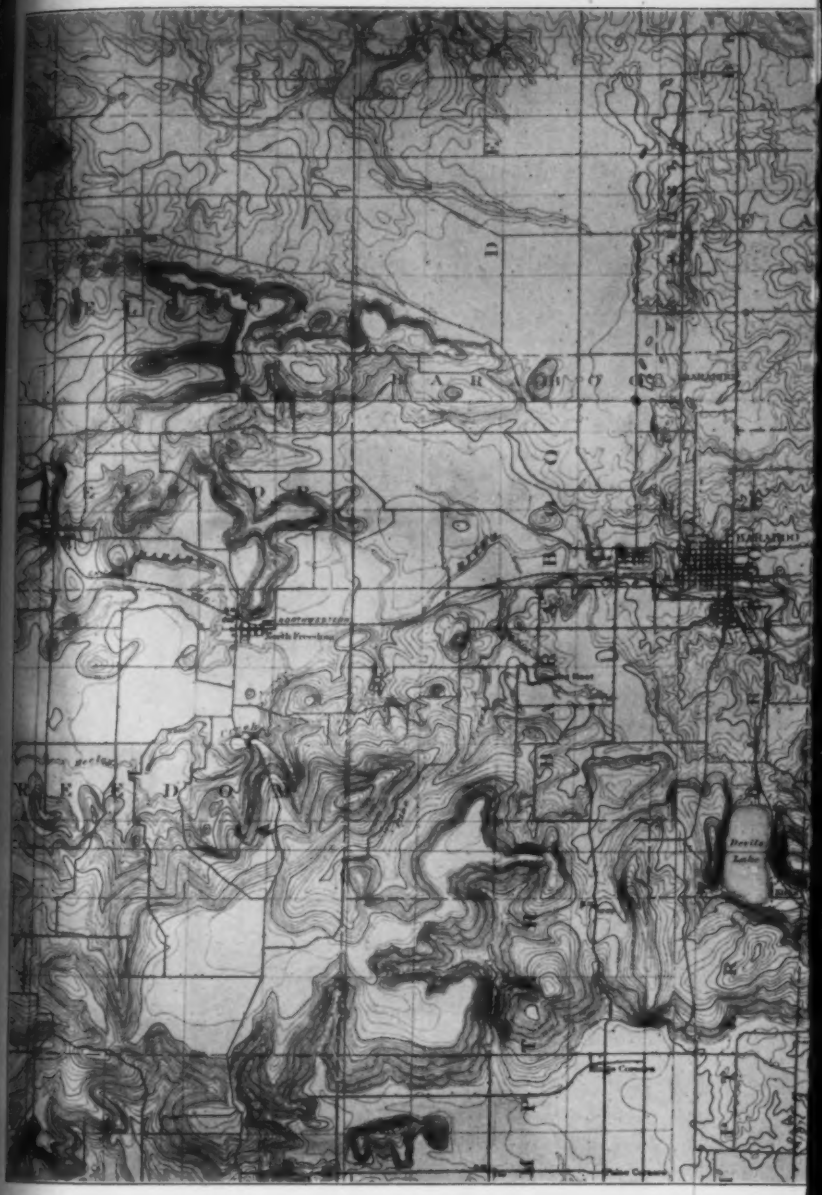
With the abandonment of the outlet, the stream from the Peck basin, which had flowed into the lake or into its outlet, chose the easier of two possible routes, avoiding the lake and flowing down the valley of the old outlet to Baraboo River. A few years ago, in order to prevent floods in its lower course, this stream was diverted again to Devils Lake by the building of a dam and the digging of a shallow ditch connecting the stream with the lake. Today the stream flows into Baraboo River or into Devils Lake, according as the temporary dam is located in the stream channel or in the artificial ditch.

The lake of today has a maximum depth of only about 40 feet, covers an area of only a little more than $\frac{1}{2}$ square mile, and is without an outlet. Its drainage basin at present is shown in Fig. 6.

SUMMARY

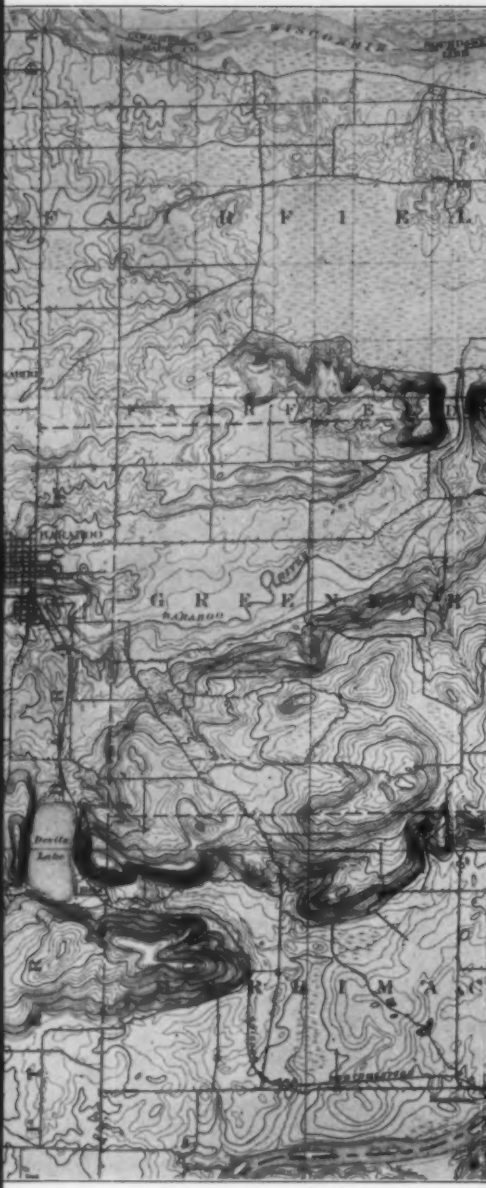
Devils Lake is seen to have had a long and complicated history. (1) Pre-Cambrian rock formations were deposited and folded. (2) Across the edges of the beds a peneplain probably was formed, over which a large stream meandered. (3) An uplift seems to have occurred and the stream intrenched itself, making a deep, curved gorge through a ridge of quartzite. (4) An early Paleozoic sea advanced over a surface of high relief and great irregularity, partially, but not completely, filling the pre-Cambrian gorge with sediments. (5) This sea withdrew at the end of the Prairie du Chien epoch, leaving a sag where the old gorge had been. (6) Conditions favoring deposition in the sea, and perhaps deposition by wind temporarily and locally, were renewed and deposition continued

until the gap was entirely filled and the pre-Paleozoic topography was buried deeply. (7) The seas finally withdrew, stream courses were developed and superimposed upon the old topography and structure, and a peneplain was developed, probably in late Tertiary time. (8) This peneplain was uplifted about 200 feet, and a second partial peneplain was developed. During this erosion cycle the Wisconsin River adjusted itself in the old gorge, and a valley about 300 feet deep was formed. (9) Another uplift to an amount of about 600 feet resulted in renewed erosion and the deepening of the gorge from 300 feet to 900 feet or more. (10) In the northern portion of the renewed gorge so formed, an ice barrier lake was formed by the edge of the Wisconsin glacier blocking the valley at two points. This lake received much glacial water, covered an area twice as large as does the present lake, was at least 270 feet deep, and had an outlet at 1,190 feet A.T., which drained northwestward. (11) With the recession of the ice, the surface of the lake dropped to about 1,020 feet and then to 970 feet, as an outlet to the north was established, and lowered through the terminal moraine dam. (12) Owing to a diversion of drainage in the Steinke and Shubring basins, decreasing the intake, and perhaps owing to changes in climate and the establishment of underground channels, the surface of Devils Lake fell from 970 to 960 feet, and the outlet was abandoned.



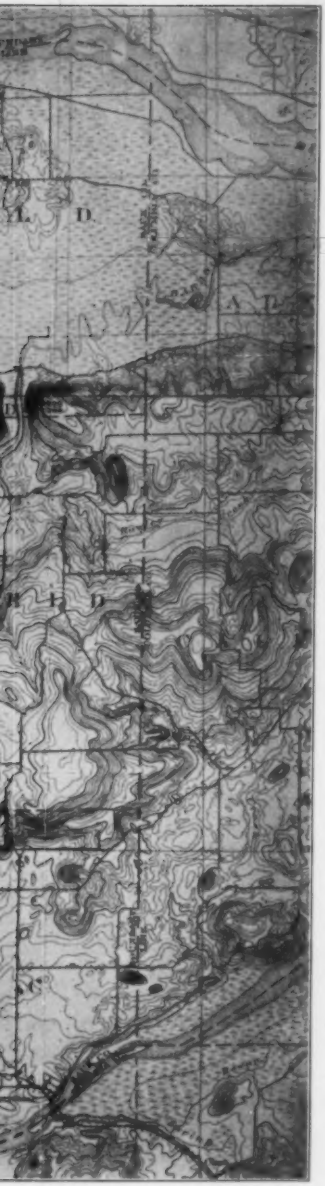
MAP SHOWING THE TOPOGRAPHIC SETTIN

Taken from the Baraboo, Briggsville, Dells, and Denzer sheets

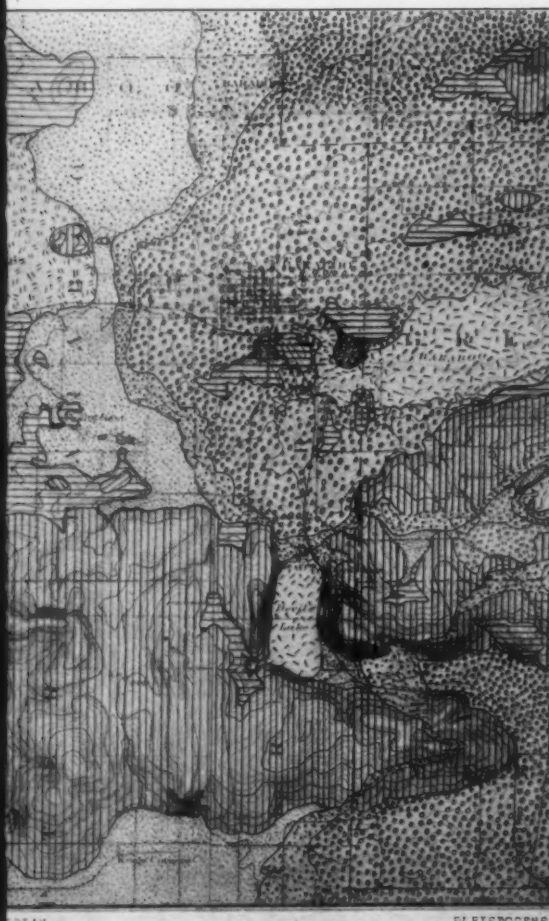


APHIC SETTING OF DEVILS LAKE

Denzer sheets of the United States Geological Survey


L.
D.
D

GEOLOGIC MAP OF THE VICINITY


ICIAN
PLEISTOCENE
St. Peter Sandstone
Terminal Moraine
Ground Moraine (only those areas are named where drift is so thick as to obscure underlying formations)
Outwash

MAP OF THE VICINITY OF DEVILS LAKE

OCENE
Glacial lake deposits
Post-Glacial lake deposits (materials deposited in lakes formed immediately after the withdrawal of the ice)

T

THE MIDDLE PALEOZOIC STRATIGRAPHY OF THE CENTRAL ROCKY MOUNTAIN REGION

C. W. TOMLINSON
University of Chicago

PART III

STRATIGRAPHY—*continued*

THE SILURIAN SYSTEM

In Utah.—This system, not including the Richmond series, is not known with certainty in the central Rocky Mountain region, except in northern Utah, where it was included by Weeks[1] under the name "Paradise limestone," which has been supplanted in official usage by the "Laketown dolomite" of Richardson.[2] Its fauna does not comprise many species, but is ample to demonstrate that the system is Silurian.[3] It is closely allied to the Niagaran faunas of other regions.

In Nevada.—This system may be represented in the upper part of the Lone Mountain limestone of western Nevada, although no diagnostic Silurian fossils have been reported from that formation. The following is an extract from Iddings' section near Modoc Peak, in the Eureka district:

3. Shaly limestone, rich in fossils. Lower part of Nevada limestone.
2. 550 feet. Light-gray siliceous limestone, with fine lines of bedding; in upper portion weathering in almost rectangular fragments; growing less siliceous toward the bottom.
1. 140 feet. Light-gray, highly crystalline, saccharoidal dolomite; not siliceous.[4]

[1] F. B. Weeks, unpublished manuscript, *U.S. Geol. Survey*.

[2] G. B. Richardson, "The Paleozoic Section in Northern Utah," *Amer. Jour. Sci.*, 4th Ser., XXXVI (1913), 406–15.

[3] Cf. E. M. Kindle, "Occurrence of Silurian Faunas in Western America," *Am. Jour. Sci.*, 4th Ser., XXV (1908), 125 ff.

[4] Arnold Hague, *op. cit.*, p. 66. Section measured by J. P. Iddings.

These descriptions show a marked resemblance to the section at Blacksmith Fork, from the lower part of the Jefferson down into the Laketown dolomite.

On the south slope of Quartz Peak in the Pahranagat Range in southern Nevada, about 140 miles south of Eureka, the Lone Mountain includes the following member:

2. 335 feet. Massive bedded dark siliceous limestone, with a stratum (not far above the base) 30 feet thick, almost made up of a species of *Pentamerus*.[1]

This, again, is strikingly like the Laketown.

Is the Laketown dolomite in part Devonian?—The uppermost member of the Laketown dolomite in the Blacksmith Fork section, 202 feet thick, is of much the same type as the Leigh formation of northwestern Wyoming. It immediately underlies beds of typical Jefferson dolomite. In the Teton River section the basal member (23 feet thick) of Blackwelder's[2] Darby (Jefferson) formation is of similar character, and is separated by an erosion surface from the underlying Leigh formation. In the Livingston Peak section there is a member, 21 feet in thickness, which is identical in type with the true Leigh, but which lies above the cliff-making Upper Bighorn dolomite, at the base of the Jefferson dolomite. In the Crandall Creek section the corresponding member, 26 feet thick, overlies a 47-foot sequence of variegated beds which lie disconformably upon the Upper Bighorn. At Livingston Peak and at Teton River, ostracods like those which are characteristic of the Leigh formation were found in this repetition of the Leigh type at the base of the Devonian system.

In brief, the uppermost member of the Laketown dolomite in northern Utah corresponds in lithologic character, and in relation to the overlying Jefferson dolomite, to the member which farther north appears to have been the introductory deposit of the first Devonian submergence. This relation suggests that the Utah member in question belongs with the Devonian rather than with the Silurian system. This interpretation has been followed in the correlation tables and diagrams accompanying this thesis, where the beds just discussed appear as Member 2 of the Devonian system.

[1] Arnold Hague, *op. cit.*, p. 196.

[2] Eliot Blackwelder, unpublished manuscript, *U.S. Geol. Survey.*

Their much greater thickness in Utah may mean that the Devonian submergence proceeded slowly northeastward from that region, or that deposition was more rapid there.

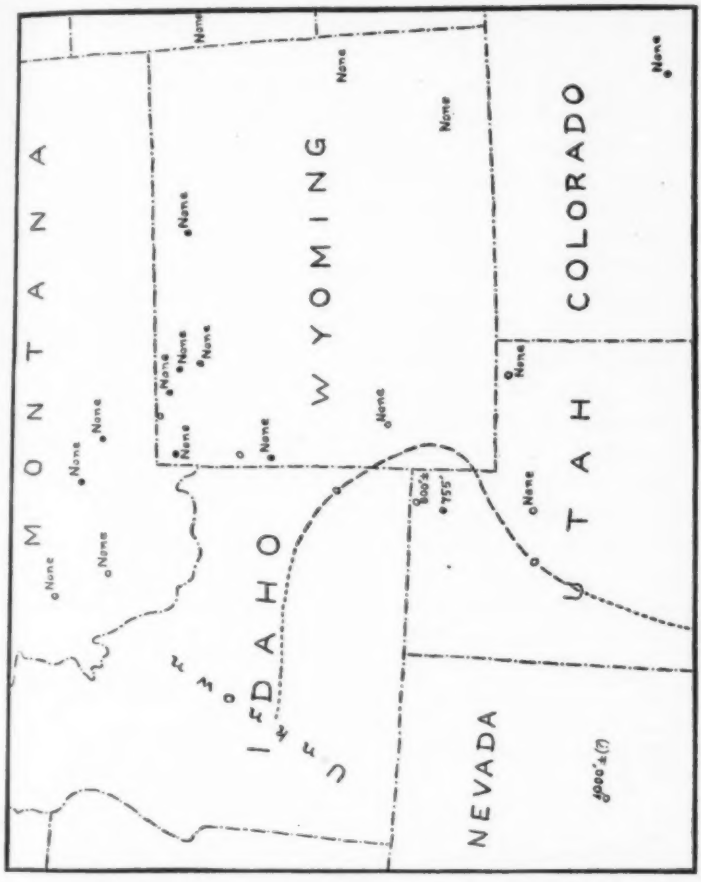


FIG. 9.—Map showing the extent and thickness of the Silurian system

Pre-Laketown and pre-Devonian emergence.—The base of the Laketown dolomite at Blacksmith Fork is clearly disconformable upon the Fish Haven formation. No evidence of a break between Silurian and Devonian has been noted in that section; and Kindle,

chiefly because of the persistance of *Halysites catenulatus* into the Jefferson dolomite, favors the idea of continuous sedimentation in this locality from Silurian into Devonian. Elsewhere in the Rocky Mountains, however, where the Silurian is absent, there was certainly an emergent interval immediately preceding the inauguration of Devonian sedimentation. The fact that no physical evidence of hiatus at that time has been noted as yet in northern Utah means little. The recurrence of *Halysites* in the Devonian certainly means no more, as regards continuity of submergence, than its persistence from the Richmond into the Silurian; yet the disconformity between the Richmond and the Silurian on Blacksmith Fork is well marked.

How far the Silurian system originally extended over the Rocky Mountain province can only be conjectured. Throughout Wyoming, wherever the Devonian occurs, it is apparent that the Silurian system, if ever represented, was completely removed by erosion prior to the Devonian submergence.

A small fauna collected by Blackwelder in the Gros Ventre Range from beds just below the Leigh dolomite was referred by Kindle and Weller to the Silurian, and by Ulrich to the Richmond.[1] The latter interpretation is probably correct, as the Leigh of the Teton Range is confidently correlated with part of the Richmond series in the Bighorn Range. Blackwelder's section in the Gros Ventres does not include beds of the types which characterize the Laketown dolomite in Utah.

The Silurian is not represented in Hintze's[2] section in the central Wasatch. The beginning of known Devonian deposition in that region was certainly preceded by an interval of emergence. Neither Silurian nor Devonian strata are known in the Uinta Range.[3]

THE DEVONIAN SYSTEM: THE JEFFERSON DOLOMITE

The basal division of the Jefferson dolomite.—The age of the beds here called Members 1 and 2 of the Devonian system has been discussed under the Silurian. Member 3, which follows 2 in

[1] Eliot Blackwelder, "Origin of the Bighorn Dolomite of Wyoming," *Bull. Geol. Soc. Amer.*, XXIV (1913), 610.

[2] *Op. cit.* [3] F. B. Weeks, *op. cit.*, XVIII (1907), 427–48.

apparent conformity wherever both are present, was the earliest development of the most characteristic Jefferson type of dolomite —dark-brown in color, saccharoidal, and giving forth a strong

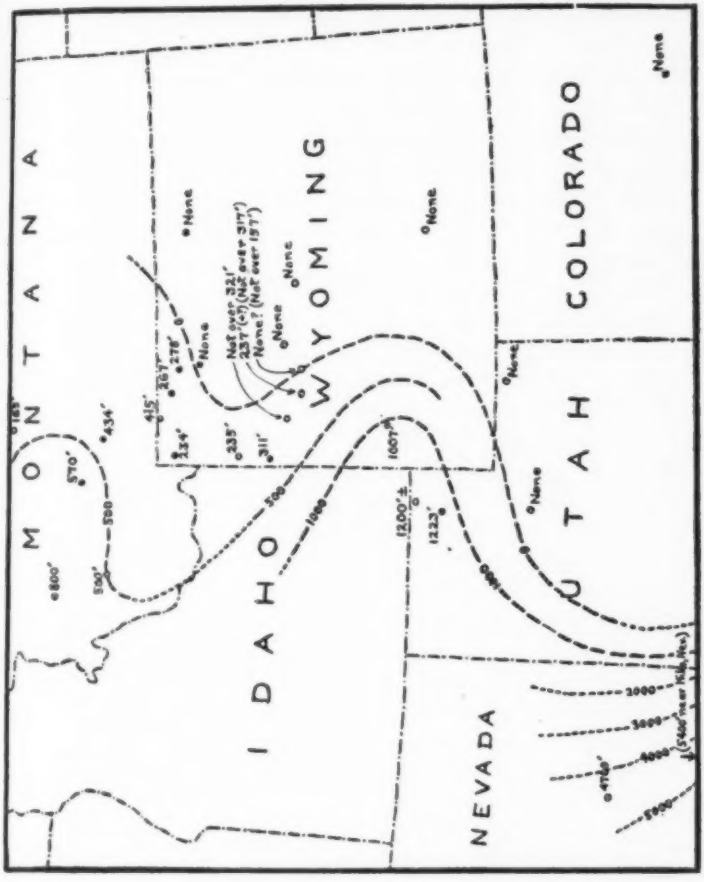


FIG. 10.—Map showing the extent and thickness of the Jefferson dolomite (Lower [?] and Middle Devonian) and correlated formations.

bituminous odor when freshly broken. The data suggesting disconformity at the top of Member 3 are summarized in the discussion of disconformities (pp. 131–34).

The main division of the Jefferson dolomite is dominated by a rather uniform succession of fairly massive, fetid, dark-brown dolomites, but includes toward its base a minor variegated sequence of thin members (4 to 8, inclusive), among which are light-colored dolomite, and locally (Labarge Mountain, Blacksmith Fork) sandstone. The correlation of these minor members on a lithologic basis has been attempted, but cannot be considered very reliable. In no two localities is there the same succession of members throughout the formation, although there is a notable degree of correspondence between the Crandall Creek and Teton River sections, for example. In the Dead Indian Creek, Livingston Peak, Logan, Labarge Mountain, and Blacksmith Fork sections the variegated members are relatively ill-developed, and the outstanding feature of the formation is a nearly uniform sequence, 200 feet thick or more, of what has been described above as the most characteristic Jefferson type of dolomites.

Members 12 to 14 of the Devonian system, above the main body of the Jefferson dolomite, are differentiated only at Blacksmith Fork and at Labarge Mountain, where they have a combined thickness exceeding 200 feet. They appear not to be represented in the sections in northwestern Wyoming and southern Montana. This fact, with certain other evidence, is strongly suggestive of an emergent interval between Members 14 and 15. (See discussion of disconformities, p. 132.)

The upper division of the Jefferson dolomite.—Member 18 is distributed with remarkable uniformity over a very wide area, and has been distinguished in nearly every locality within the scope of this thesis where the Jefferson dolomite has been described in any detail. Its brecciated structure, together with an abundance of calcite geodes in some places, give its weathered surfaces a characteristic nodular, pitted appearance. It is everywhere separated from the main mass of the Jefferson by a sequence of thin-bedded, largely platy dolomites. At Labarge Mountain the base of this sequence is marked by 10 feet of sandstone (Member 15); and in the Teton River section its lower portion contains some thin beds of sandstone, and quartz grains are scattered through several of the beds of dolomite.

This upper division of the Jefferson, as indicated by the correlation diagrams, maintains a fairly constant development even where the main body of the formation beneath it shows much variability.

The beds doubtfully referred to Member 18 in the Goose Creek Ridge and Rattlesnake Mountain sections are not typical of that member, but resemble it in being massive and in underlying a series of thin-bedded dolomites which possess all the essential characters of Member 19. (See discussion of the Three Forks formation, pp. 383–84.) It is perhaps more likely that the beds in question really belong to the Richmond series.

Misuse of the name "Jefferson" in Yellowstone Park and vicinity.—The name "Jefferson" was first used by Peale[1] to describe the dark limestones overlying the Gallatin formation in the Three Forks quadrangle, Montana. The strata included by Peale under that name are now believed to be entirely of Devonian age.[2] As they comprise everything between the Gallatin formation below and the Three Forks shale above in the type locality of the formation, it was natural for other geologists to apply the name "Jefferson" to all the strata between those two formations in neighboring areas. In the Livingston quadrangle,[3] Montana, and in the Absaroka[4] quadrangles, Wyoming, however, Hague confined the name "Jefferson" to the strata which he regarded as Silurian, and extended the name "Three Forks" to include all the limestones carrying Devonian fossils. Iddings and Weed, in Yellowstone Park,[5] employed the names in similar fashion, but not altogether consistently in different parts of the Park.

With the aid of his own field notes, and by as careful a correlation of members as the published descriptions permit, the writer

[1] A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U.S. Geol. Survey, Bull. 110* (1895).

[2] E. M. Kindle, letter of March 29, 1916; Edwin Kirk, letter of June 13, 1915.

[3] Arnold Hague, "Description of the Livingston Sheet," *Geol. Atlas U.S.*, Folio 1 (1894).

[4] Arnold Hague, "Description of the Absaroka Quadrangle," *Geol. Atlas U.S.*, Folio 52 (1899).

[5] J. P. Iddings and W. H. Weed, "Descriptive Geology of the Gallatin Mountains," *U.S. Geol. Survey, Monographs*, XXXII, Part 2 (1899), chap. i; "Descriptive Geology of the Northern End of the Teton Range," *ibid.*, chap. iv; W. H. Weed, "Geology of the Southern End of the Snowy Range," *ibid.*, chap. vi.

has prepared the accompanying tentative correlation table (Fig. 11) of the sections measured by Iddings and Weed, adding three of his own sections for comparison. The "Jefferson" of Hague, Iddings, and Weed is seen to include the Bighorn dolomite as its chief

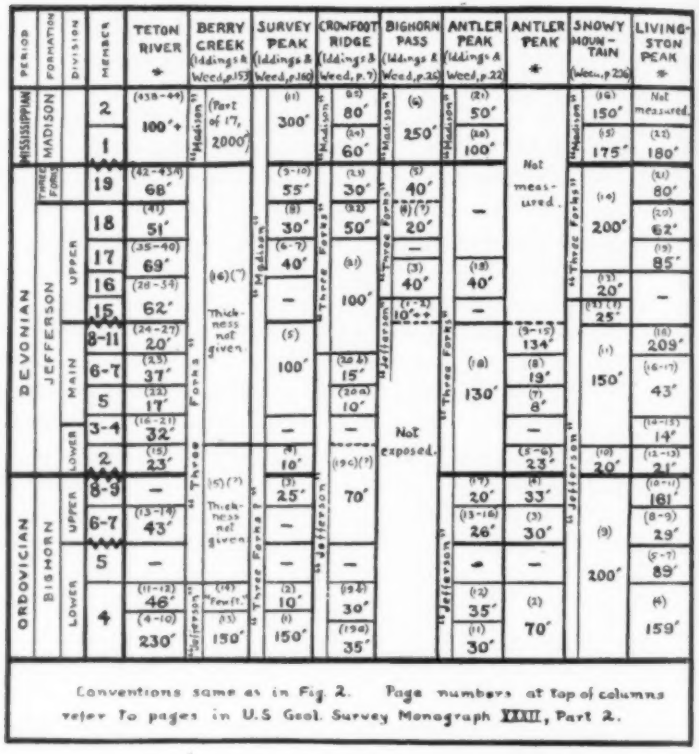


FIG. 11.—Tentative correlation table for sections in Yellowstone Park and vicinity

constituent, and their "Three Forks limestone" consists chiefly of beds which are properly to be correlated with part of the true Jefferson dolomite as originally defined by Peale. The Devonian fossils identified by Girty[1] from Yellowstone Park came from beds

[1] G. R. Girty, "Devonian and Carboniferous Fossils of the Yellowstone National Park," *U.S. Geol. Survey, Monographs*, XXXII, Part 2 (1899), chap. xii.

well down in the Jefferson formation, which explains their likeness to the Jefferson fauna known from other regions.[1] The variability of the Three Forks formation from shale to limestone along the strike has been overestimated because of this same erroneous correlation.

Correlation of the Jefferson dolomite with the Nevada limestone.—The Jefferson dolomite, as known in Montana and northern Utah, has been correlated definitely by Kindle[2] with the Nevada limestone of eastern Nevada, on paleontological grounds. Of the eleven specifically identified forms described by Kindle from the Jefferson formation, other than new species, seven were described by Walcott[3] from the Nevada limestone. Of the 32 forms partially or completely identified by Kindle from the Jefferson Limestone, only three are of genera not described by Walcott from Nevada.

The total thickness of the Nevada limestone is estimated by Hague[4] at 6,000 feet. Although accuracy is not claimed for this figure, it cannot be doubted that the Nevada is very much thicker than any described section of the Jefferson limestone. The following figures are given by Hague for the thickness of the Nevada limestone at various localities in the Eureka district:

Newark Mountain[5] (Bed 5): 3,500 feet. Considered by Hague[6] to be less than (the upper) half of the total thickness of the formation. A small Upper Devonian fauna was collected "several hundred feet below the top."

Near Modoc Peak[7] (Beds 3–18): 4,710 feet. (Hague regarded the Nevada as including more than 700 feet of lower strata also.) Rich Lower Devonian fauna in lower 425 feet (Beds 3–4); no fossils other than "*Stromatopora*" and "*Chaetetes*" found at higher horizons.

East of Lamoureux Canyon[8] (Beds 1–5): 3,000 feet, top not exposed. Basal 200 feet carries a rich Lower Devonian fauna.

County Peak:[9] 4,500 feet. Fossils at three horizons.[10]

[1] Cf. E. M. Kindle, "Fauna and Stratigraphy of the Jefferson Limestone in the Northern Rocky Mountain Region," *Bull. Amer. Pal.*, IV, No. 20 (1908), 22.

[2] *Ibid.*, pp. 20–21.

[3] C. D. Walcott, "Paleontology of the Eureka District," *U.S. Geol. Survey, Monographs*, VIII (1884).

[4] Arnold Hague, "Geology of the Eureka District, Nevada," *U.S. Geol. Survey, Monographs*, XX (1892), 13, 63–64.

[5] *Ibid.*, pp. 82, 158.

[6] *Ibid.*, p. 158.

[7] *Ibid.*, p. 66.

[8] *Ibid.*, p. 67.

[9] *Ibid.*, p. 68.

[10] *Ibid.*, pp. 78–80.

The occurrence of such great thicknesses at four distinct localities renders it unlikely that the true thickness has been greatly overestimated because of duplication by faulting.

The two chief fossiliferous horizons in the Nevada limestone are near the base and near the top, and are separated by from 2,000 to 4,000 or more feet of strata which have yielded no diagnostic fossils. The fauna described by Kindle from the Jefferson limestone includes 10 forms[1] (2 of which are specifically identified) which occur only in the lower part of the Nevada limestone, 4[2] (3 of which are specifically identified) which occur in both the upper and the lower horizons, and 5[3] (2 of which are specifically identified) which occur in the upper part of the Nevada only. Although this evidence is meager, it suggests that the Jefferson limestone includes representatives of both the basal and upper parts of the Nevada limestone. It is possible that the disconformity between Members 14 and 15 of the Jefferson, for which evidence is cited on page —, represents a large part of the barren middle portion of the Nevada. This would mean that the greater thickness of the Nevada, as compared with the Jefferson, was due, at least in part, to the presence in the Nevada of members which either never were deposited in the Rocky Mountain province or were eroded from that region in Devonian time; that during the Devonian period the eastern part of the Great Basin was more persistently submerged or less elevated in emergent intervals (or both) than was the central Rocky Mountain Region.

In the Pahranagat Range, west of Hiko, in southeastern Nevada, Walcott[4] measured a section including 5,400 feet of strata which he assigned to the Devonian. From this sequence he obtained 22 fossil forms, to 9 of which he assigned definite specific names. All of these forms are identical, according to Walcott's lists, with

[1] *Favosites* sp., *Chonetes* cf. *macrostriata*, *Stropheodonta* sp., *Schuchertella chemungensis*, *Athyris* sp., *Platyceras* sp., *Actinopteria* sp., *Loxonema approximatum?*, *Loxonema nobile*, *Bythocypris?* (*Leperditia?*) sp.

[2] *Stromatopora* sp., *Productella* cf. *spinulicosta* (*Productus subaculeatus*), *Atrypa reticularis*, *Martinia maia*.

[3] *Spirifer utahensis* Meek (*S. disjunctus* Sowerby), *S. engelmanni* Meek, *Pterinopecten* sp., *Naticopsis* sp., *Pleurotomaria* sp.

[4] Arnold Hague, *op. cit. ult.*, pp. 197–99.

species found in the Nevada limestone in the vicinity of Eureka—some in the lower, some in the upper, fossiliferous horizon there.

THE DEVONIAN SYSTEM: THE THREE FORKS FORMATION

Type sections.—As defined by Peale[1] in the type sections in the Three Forks quadrangle, Montana, this formation includes all strata between the top of Member 18 of the Jefferson dolomite and the base of the Madison limestone (Mississippian). Raymond[2] has collected and studied large faunas from several horizons in the type locality opposite Logan. Haynes[3] has carried on Raymond's work, and studied in detail the stratigraphy of the formation in all exposures within about twenty miles of Logan.

Members 19 and 20.—The chief fossiliferous zone of the Three Forks, Member 20 of the Devonian system (Members 4 and 5 of Haynes) has not been identified in Montana east of the Three Forks quadrangle, nor anywhere in Wyoming. It is quite possible that outliers of it may yet be found in those areas, however, as Member 19 is widely distributed there. The top of the Jefferson dolomite is clearly marked in nearly every section in western Wyoming and southwestern Montana by the massive, brecciated Member 18. Were it not for this, the beds of Member 19 might easily be confused with those of Member 17, to which they bear much likeness. In the Dead Indian Creek section, where Member 18 was not recognized, certain strata were assigned to Member 19 because their relation to overlying strata corresponds to the relation of Member 19 to overlying beds in the Crandall Creek section, where Member 18 is present.

Beds of doubtful age in the Bighorn Range, and near Cody.—In the Goose Creek Ridge and Rattlesnake Mountain sections there is a belt of platy buff and yellow dolomites and calcareous shales

[1] A. C. Peale, "The Paleozoic Section in the Vicinity of Three Forks, Montana," *U.S. Geol. Survey, Bull. 110* (1893).

[2] P. E. Raymond, "On the Occurrence in the Rocky Mountains of an Upper Devonian Fauna with *Clymenia*," *Amer. Jour. Sci.*, XXIII (1907), 116–22; "The Fauna of the Upper Devonian of Montana," *Annals of the Carnegie Museum*, V (1909), 141–58; "The *Clymenia* Fauna in the American Devonian," *Proc. Seventh Intern. Zoöl. Cong.* (Boston, 1907).

[3] W. P. Haynes, *op. cit.*, pp. 13–54.

between the top of the fossiliferous Bighorn and the base of the typical Madison, which corresponds closely in lithological character with Member 19 as developed farther northwest. In the Bighorn

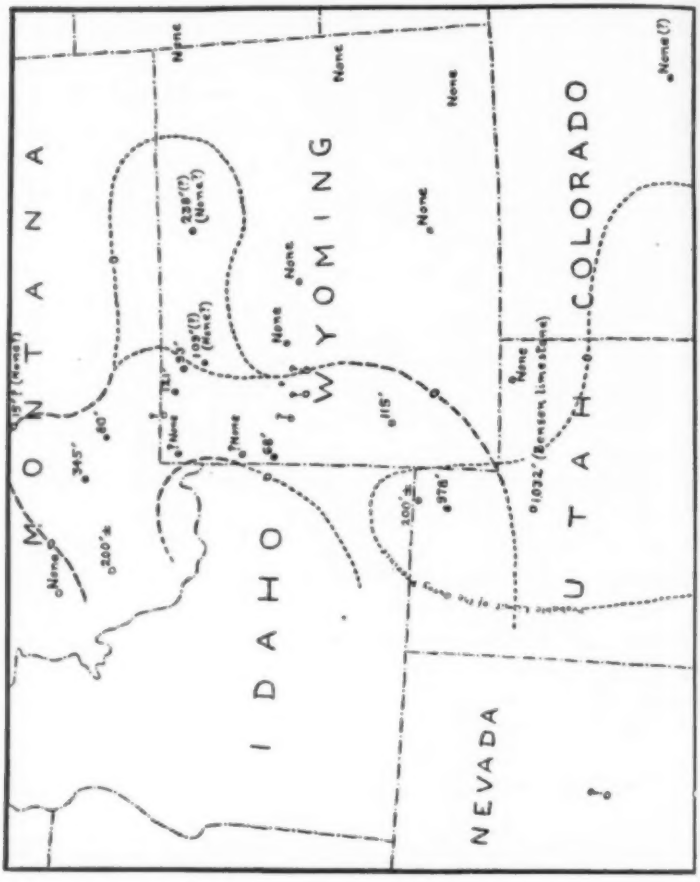


FIG. 12.—Map showing the extent and thickness of the Three Forks (Upper Devonian) and correlated formations.

Range, where this belt is 238 feet thick, it was considered by Darton[1] to be the basal member of the Madison limestone; but it is unlike

[1] N. H. Darton, "Description of the Bald Mountain and Dayton Quadrangles," *Geol. Atlas U.S.*, Folio 141 (1906), p. 4; Goose Creek section.

any part of the true Madison seen by the writer elsewhere. So far as known, it is wholly barren, as is likewise Member 19. It may belong to the Richmond series. However, if the Devonian system is represented in the sections named, it includes this belt, and possibly the underlying massive member which separates it from the fossiliferous Upper Bighorn.

Member 21, comprising black shales overlain by yellow or red aranaceous strata, is found at Crandall Creek and Dead Indian Creek in the Absaroka Range with a development almost precisely like that shown in most of Haynes's sections near Three Forks. Haynes[1] considers that the fauna of this member is transitional to the Mississippian.

The Three Forks formation in northern Utah; correlation with the Benson and Ouray limestones.—Richardson[2] reports very poor exposures of the Three Forks formation in the Randolph quadrangle in northern Utah, with red shaly limestone (Member 19?) as the most conspicuous element in the float. The fauna collected by him from this formation, and identified by Kindle, indicates a mingling of Ouray and Three Forks species. Five[3] of the 7 species in Richardson's list occur also in the Devonian fauna of the Ouray limestone in Colorado,[4] and 6[5] of the 7 occur in the Three Forks formation of the type area.

Haynes[6] has noted the probability of a correlation between the Three Forks and the lower (i.e., the Devonian) part of the Ouray. Of 25 species and varieties of brachiopods listed by Kindle[7] from the latter horizon, and of 27 listed by Haynes[8] from "Bed 5" (part of Member 20 of this paper) of the former, there are 11 which occur in both lists.

[1] *Op. cit.*, pp. 21, 28. [2] *Op. cit.*, p. 412.

[3] *Camarotoechia* cf. *contracta*, *Productella coloradensis*, *Schizophoria striatula* var. *australis*, *Spirifer whitneyi* var. *animasensis*, and *Spirifer notabilis*.

[4] E. M. Kindle, "The Devonian Fauna of the Ouray Limestone," *U.S. Geol. Survey, Bull. 391* (1909).

[5] *C. contracta*, *P. coloradensis*, *S. striatula* var. *australis*, *S. whitneyi* var. *animasensis*, *Syringothyris* cf. *carteri*, *Cleiothyridina* sp.

[6] *Op. cit.*, p. 24.

[7] E. M. Kindle, "The Devonian Fauna of the Ouray Limestones," *U.S. Geol. Survey, Bull. 291* (1909), p. 12.

[8] *Op. cit.*, p. 25.

Richardson[1] estimates the thickness of the Three Forks formation in the Randolph area at 200 feet. In the Blacksmith Fork section both the upper and the lower limits of the Three Forks are marked by the usual sharp lithologic contrasts, yet the strata between the Jefferson and the Madison total 978 feet in thickness. For the most part, this sequence is composed of the usual Three Forks types; but between the green shales below and the black shales above there appears a 360-foot belt of blue-gray limestones (Member 20B).

Less than ten miles south of the above section, in the canyon east of Paradise P.O., Utah, Kindle[2] noted no representative of the Three Forks formation. In the region east of Ogden such a representative is probably to be found, as suggested by Richardson,[3] in the reddish shales and thin-bedded limestones mentioned by Blackwelder,[4] which are 250 feet thick on the South Fork of Ogden River.

In the South Fork of Big Cottonwood Canyon, about 75 miles south of Blacksmith Fork, occurs the Benson limestone of Hintze,[5] comprising 1,032 feet of blue limestone. From a horizon in the upper part of this formation Hintze collected a fauna which is very like that of the Ouray limestone. His description of the Benson indicates that it is lithologically very different from the typical Three Forks. The belt of blue-gray limestones in the middle of the Three Forks formation at Blacksmith Fork, and the upper division of the Jefferson dolomite in the same section, correspond roughly in character with the Benson. This fact, together with the mingled Ouray–Three Forks fauna found in the Randolph quadrangle, suggests the possibility that the Ouray lithologic type dovetails into the Upper Devonian rocks of the more northern and western province.

[1] G. B. Richardson, *op. cit.*, p. 412.

[2] E. M. Kindle, "The Fauna and Stratigraphy of the Jefferson Limestone in the Northern Rocky Mountain Region," *Bull. Amer. Pal.*, IV, No. 20 (1908), 16.

[3] *Op. cit.*, p. 412. Also Eliot Blackwelder, letter of April 29, 1915.

[4] Eliot Blackwelder, "New light on the Geology of the Wasatch Mountains, Utah," *Bull. Geol. Soc. Amer.*, XXI (1910), 528–29.

[5] F. F. Hintze, Jr., *op. cit.*, pp. 88–142.

SUMMARY OF RESULTS ON SPECIAL PROBLEMS OF INVESTIGATION

The following progress has been made toward the solution of the four special problems noted in the foreword of this thesis:

1. *The Age of the "Jefferson dolomite" in the Livingston, Yellowstone National Park, and Absaroka quadrangles.*—It has been shown beyond doubt that the Ordovician Bighorn dolomite is present, and characteristically developed, throughout the Absaroka Range, as far north as Livingston Peak in Montana, and in Yellowstone Park. It was included in the "Jefferson dolomite" of Hague, Iddings, and Weed. It is followed disconformably by the true Jefferson dolomite (Devonian), much of which was erroneously included by earlier writers under the name "Three Forks formation."

2. *Middle Paleozoic disconformities.*—A well-marked disconformity between the Lower (Trenton) and Upper (Richmond) divisions of the Bighorn dolomite has been discovered in the Absaroka Range. In northwestern Wyoming and southwestern Montana the existence of disconformities at the base of the Bighorn dolomite and at the base of the Jefferson dolomite has been established. Much evidence has been gathered which points toward the existence of disconformities at at least one horizon within the Jefferson dolomite, and at the base of the Mississippian system.

3. *Correlation of Upper Cambrian and Ordovician formations in Wyoming with those in Utah.*—The Upper and Lower divisions of the Fish Haven dolomite in northern Utah have been shown to correspond in lithologic character to the Upper and Lower divisions, respectively, of the Bighorn dolomite; and there is evidence of a disconformity between the two divisions of the Fish Haven dolomite, as well as between those of the Bighorn. Several members of the Gallatin formation of Wyoming and Montana have been tentatively correlated on lithologic grounds with members of the St. Charles formation (Upper Cambrian) in northern Utah, and the main flat-pebble conglomerate zone at the top of the Gallatin is tentatively correlated with a member of similar character in Utah which includes the top of the St. Charles formation and the lower part of the Garden City (Beekmantown) formation.

4. *Relation of Ordovician to Silurian in Utah.*—In the vicinity of Blacksmith Fork, northern Utah, the Laketown dolomite (Silurian) has been found to be separated from the underlying Upper Fish Haven dolomite (Richmond) by a well-marked disconformity.

HISTORICAL SKETCH

UPPER CAMBRIAN AND LOWER ORDOVICIAN

Extent of submergence.—The present extent and variations in thickness of the sediments deposited in the central Rocky Mountain region during the Upper Cambrian-Lower Ordovician submergence are shown in Fig. 7. It will be noted that this is not a paleogeographic map in the usual sense, as no attempt has been made to indicate the original extent of these sediments, other than to show them as continuous across relatively small areas, from which they have certainly been removed by post-Cretaceous erosion.

The much greater thickness of this group of sediments in western and northern Utah and in Nevada, as compared with Wyoming and Montana, means either that (1) sedimentation continued longer or (2) took place more rapidly in the first-named region, or that (3) during the succeeding interval of emergence erosion removed a larger part of the series in question from Wyoming and Montana than from the adjoining region to the southwest. Certainly the first and last, and perhaps all three, of these factors combined to produce the net result. A logical supposition is that the sea retreated from northeast to southwest, so that deposition continued in the Great Basin after erosion had begun on recently emerged areas in Wyoming and Montana. The wide-spread uniformity in type of the sediments in question indicates a similarly extensive uniformity of conditions of deposition, and suggests that the second factor was not of great importance.

Paucity of clastic sediments.—The beginning of the Upper Cambrian transgression in Utah was marked by a deposit of sand of varying thickness. From that time until the close of the Beekmantown epoch no part of the region in which the St. Charles, Garden City, Gallatin, and Upper Deadwood formations are found

received any notable quantity of arenaceous sediment, so far as the record now shows. During long intervals the deposits accumulating on the floor of the clear sea which covered this area were nearly or quite without clastic ingredients. At no time was clastic mud brought in in such quantity as greatly to preponderate over calcareous matter. This condition makes it certain that there were no high shores, nor debouchures of streams draining areas of high relief or dry climate, in or very near to the region under consideration.

Evidence that the sea was shallow.—The intraformational conglomerates which characterize the upper part of the Upper Cambrian and much of the Beekmantown series record the fact that the seas of that time were shallow enough to permit the breaking and movement, by waves or currents, of freshly or partly consolidated sediments on the sea bottom.

The Chazyan(?) sands.—Somewhat later in the Ordovician period, probably in the Chazyan epoch, a flood of sand swept over the extreme northern part of Utah and much of eastern Nevada (see Fig. 8). This was probably the result of an uplift of neighboring lands, perhaps in central or eastern Utah.

Emergence and peneplanation.—Subsequently, the entire region shown in the accompanying maps (Figs. 6–10, 12, 13) emerged and the freshly exposed sediments were subjected to extensive erosion, which continued until about the close of the Black River epoch. This emergence took place without any appreciable deformation of the Cambrian and early Ordovician sediments. Probably it produced no great relief in the region where those sediments are known. The first deposits of the succeeding submergence were laid down on a surface whose relief probably did not exceed 200 feet in all northern and western Wyoming, and on which, in that region, slopes as steep as 10° were, so far as known, nowhere more than a few feet or yards in length. Either the relief was not greater than this at any time during the interval of emergence or a rougher surface was reduced to this condition by stream erosion during that interval, with the aid of marine planation at the border of the advancing Middle Ordovician sea.

MIDDLE AND UPPER ORDOVICIAN

The Trenton submergence.—About the end of Black River time the sea readvanced into the central Rocky Mountain region, probably from the west. The area known to have been covered by this inundation in Utah and Wyoming is approximately the same as in the case of the Late Cambrian submergence (see Fig. 9). Locally, in Wyoming a little sand was deposited in depressions of the surface as the sea-border transgressed the region; but the main body of limestone which represents this Trenton submergence is wholly free from arenaceous and shaly matter. The seas were even more persistently clear than in Upper Cambrian time.

The masses of calcareous algæ which make up much of the Lower Bighorn and Lower Fish Haven dolomites bear witness to the prevalent shallowness of the water.

The post-Trenton emergence.—Sedimentation was interrupted by emergence between Trenton and Richmond times, but the erosion accomplished during this interval seems to have been slight. If any considerable thickness of strata was removed at this time, no remnants of them have been recognized. It is probable that the land was not uplifted much above the base level of the streams which drained its surface.

The Richmond submergence.—With the return of the sea in the Richmond epoch the processes of deposition were resumed under conditions similar to those which obtained during the Trenton epoch. The seas remained clear until the end of the Ordovician record. As in the case of the Upper Cambrian formations, the Bighorn and Fish Haven dolomites present no evidence, aside from the sandstone locally found at the base of the Bighorn, of proximity to shore lines. The original extent of the Bighorn formation was probably much greater than the area in which it now is found. The long period of emergence which followed its deposition afforded ample opportunity for erosion.

SILURIAN

Emergence.—During the early part of the Silurian period (Medina and Clinton epochs) the entire central Rocky Mountain region was above sea. The emergence, like the two or three next

preceding ones, was accomplished, so far as the known record shows, without crustal deformation. In Wyoming, Montana, and Colorado, this interval of emergence may have continued without interruption until Devonian time.

The Niagaran(?) invasion.—Toward the middle of the period, probably in the Niagaran epoch, the sea invaded this region again, from the Great Basin side. The sediments deposited in this sea are known only in northern Utah (and in Nevada?), but may once have been far more extensive (see Fig. 10). The *Conchidium knighti* fauna found in the Laketown dolomite implies a marine connection with Alaska and with Europe.

DEVONIAN

Pre-Jefferson erosion.—The Jefferson dolomite overlaps far beyond the Laketown dolomite into western Wyoming and southwestern Montana. In Wyoming it rests upon various horizons of the Upper Bighorn dolomite. In Montana, north and west of Livingston, it lies directly upon the Upper Cambrian. It is probable that the Bighorn dolomite once extended farther into Montana, and was removed by pre-Jefferson erosion. If the Silurian system originally extended into Wyoming or Montana, it also must have been removed at this time. In Utah, no evidence of a hiatus between the Silurian and the Devonian has been noted.

Although the Jefferson dolomite overlaps both the Silurian and the Ordovician systems, the surface upon which the first sediments of the Jefferson dolomite were deposited appears to have been almost as level as that on which the Lower Bighorn dolomite was laid down. A suggestion of relief is furnished by the contrast between the sections at Logan and Livingston, Montana. Near Logan, the Jefferson rests upon Member 3 of the Cambrian system. At Livingston Peak, about 50 miles to the east, 438 feet of Bighorn dolomite intervene between the Jefferson and that member. Even this difference indicates but an inappreciable slope.

Devonian marine invasions.—The Devonian submergence, during which the Jefferson dolomite was deposited, was probably interrupted in Wyoming and Montana by at least one interval of emergence. The sea appears to have made two or three successive

advances from Nevada northeastward, so that the thickness of its deposits diminishes toward the northeast because of both a progressively shorter total duration of sedimentation in that direction and, correspondingly, a progressively longer duration of the intervening emergences, with accompanying erosion. A small amount of sand, diminishing toward the northeast, was deposited in the shoreward portion of the sea during each advance. Aside from this, little or no clastic material was laid down in the Devonian sea in the central Rocky Mountain region until the later part of the period.

The Upper Devonian muds.—In the Upper Devonian the calcareous sediments accumulating on the sea bottom in Utah, Wyoming, and Montana (see Fig. 12) were polluted by an influx of mud, which in Utah attained a thickness of several hundred feet. The Three Forks formation comprises the resulting shales and limestones, together with a small thickness of arenaceous sediments, only locally present, which may date from the beginning of the Mississippian submergence rather than from the close of the Devonian. The sea which occupied parts of Colorado and central Utah in Upper Devonian time seems to have been connected directly with the Three Forks sea for a short time only, near the middle of the epoch.

THE PRE-MISSISSIPPIAN INTERVAL OF EMERGENCE

Depth of erosion.—It is certain that all of Wyoming, most of Montana, and much of Colorado was above sea-level and undergoing erosion at the close of the Devonian period. The Lower Mississippian sediments (Madison limestone) overlap all older Paleozoic formations (see Fig. 13). The gradual truncation of the Bighorn dolomite and the upper part of the Deadwood formation by the Madison limestone in the southern part of the Bighorn Range is clearly due to pre-Mississippian erosion, and the varying thickness of the Three Forks formation in northwestern Wyoming and part of southwestern Montana is due to the same cause. The relief of the final surface on which the Madison limestone rests, however, is nowhere very pronounced.

Where the Mississippian strata rest upon Ordovician rocks a part of the hiatus may be attributed to erosion during Silurian and

early Devonian time; and where they lie on the Cambrian, the pre-Bighorn emergence also must be reckoned with. Again, it is probable that parts of the region never were covered by strata of the

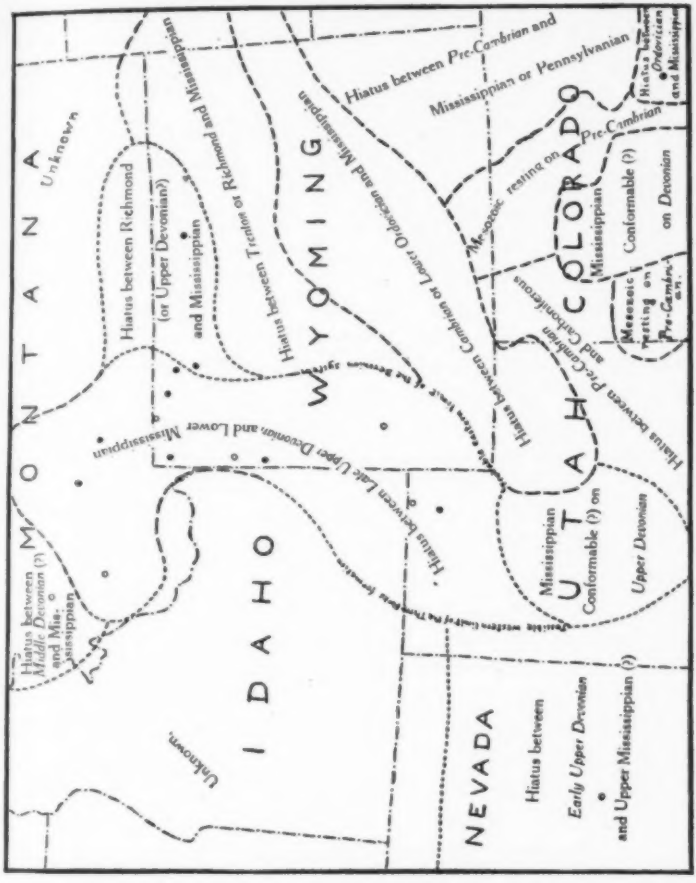

MONTANA
Unknown
Hiatus between Richmond (or Upper Devonian?) and Mississippian
Hiatus between Trenton or Richmond and Mississippian
Hiatus between Pre-Cambrian and Mississippian or Pennsylvanian
WYOMING
Hiatus between Cambrian or Lower Ordovician and Mississippian
Mesozoic resting on Pre-Cambrian
COLORADO
Mississippian Conformable (?) on Devonian
Mesozoic resting on Pre-Cambrian
Hiatus between Pre-Cambrian and Cambrian or Unconformable
UTAH
Hiatus between Lower Ordovician Lake Beds and Upper Devonian and Lower Mississippian
Hiatus between Upper Devonian Lake and Mississippian
Hiatus between Middle Devonian (?) and Mississippian
IDAHO
Unknown
Mississippian Conformable (?) on Upper Devonian
NEVADA
Hiatus between Early Upper Devonian and Upper Mississippian (?)

FIG. 13.—Map showing the length of the pre-Mississippian hiatus in the central Rocky Mountain region

age of some of the formations which appear elsewhere. The extreme view, that none of the existing Middle Paleozoic formations ever extended much beyond their present limits, is certainly not true in the central Rocky Mountain region. The other extreme,

that every one of them once extended over the whole area and was cut back by erosion before the Mississippian period, is likewise, in all probability, incorrect.

"Positive" and "Negative" areas; axes of warping.—Whatever was the true proportion between erosion and non-deposition, the net result is shown in Fig. 13, which is, in effect, a paleo*geologic* map of the central Rocky Mountain region at the close of the pre-Mississippian interval of emergence. If the area of Cambrian and pre-Cambrian rocks which then extended from eastern Utah northeastward across southern Wyoming and northern Colorado owed its exposure to the erosion of Middle Paleozoic formations during emergent intervals, it certainly was more exposed to erosion during those intervals than were the adjacent areas on either side of it—probably because of greater altitude. If its exposure was due wholly to non-deposition of the Middle Paleozoic formations, then it must have been above water when neighboring areas were submerged. In either case, or under any hypothesis which combines the two views, *this area of Cambrian and pre-Cambrian rocks must have been at a greater average altitude* during Middle Paleozoic time than the areas on either side of it.

The major axis of this area of upward tendency is approximately at right angles to the average trend of the Rocky Mountain folds. The downward-tending belt, which is known to have been covered by most of the Middle Paleozoic seas, extends in parallel fashion from the northern part of the Great Basin northeastward across the Rocky Mountain province. This is well illustrated by the distribution of the Bighorn dolomite (see Fig. 9).

The trend of these belts indicates the direction of axes of warping merely, not of true orogeny.

The pre-Mississippian interval of emergence was brought to a close by an invasion of the sea, whose deposits are more widespread in the central Rocky Mountain region than are those of any preceding submergence.

Reviews

Mineral Deposits of the Santa Rita and Patagonia Mountains, Arizona. By FRANK C. SCHRADER, with contributions by JAMES M. HILL. U.S. Geol. Survey, Bull. 582, 1915. Pp. 373, pls. 25.

This report covers an area of some 1,400 square miles extending north and east from the city of Nogales, Arizona, on the Mexican border. The mountain groups are short, irregular ranges bordered by broad, sloping plains of Quaternary gravels. Mesozoic granite, quartz diorite, and quartz monzonite, granite porphyry and aplite, with Tertiary andesite, rhyolite, and bedded tuffs and agglomerates, constitute the two groups of igneous rocks which outcrop over about two-thirds of the mountainous area. The remaining third is occupied by a thick sequence of Cretaceous (?) shales unconformably underlain by Carboniferous and Devonian limestones and older shales and quartzites.

The chief mineralization in this area accompanied or followed the Mesozoic intrusions. Silver, copper, gold, and lead are the leading metals. Fissure veins, contact-metamorphic deposits, replacement deposits, and gold placers are all of notable importance. Copper is the most important metal in the contact deposits, while silver and lead dominate in the replacement type, which is here rather carefully distinguished from the contact deposits proper. The average depth of ground-water level and of the oxide zone is about 250 feet.

C. W. T.

Some Mining Districts in Northeastern California and Northwestern Nevada. By JAMES M. HILL. U.S. Geol. Survey, Bull. 594, 1915. Pp. 196, pls. 12.

This is a report on a reconnaissance of nineteen widely scattered mining districts below first rank in present-day importance, sixteen of them in Nevada and three in California The chief value of the work will be to those who are specially interested in the development of one or more of these districts, though a number of points of general interest in economic geology are brought out.

Gold-silver, silver-lead, copper, and antimony deposits are described. Two epochs of mineralization are recognized, the first following the intrusion of a group of granitoid rocks in late Cretaceous or early Tertiary time, the second following the extrusion of a group of later Tertiary andesites and rhyolites. Most of the ores are believed to date from the former epoch. The gold-silver and silver-lead ores are vein deposits. Most of the copper ores are replacements of sedimentary rocks in the vicinity of monzonitic intrusives.

A number of good examples of magmatic differentiation are described.

C. W. T.

"A Geologic Reconnaissance of the Cuzco Valley, Peru." By HERBERT E. GREGORY. *Am. Jour. Sci.*, XLI (1916), pp. 1–100, pls. 2, figs. 44. Contributions from the Peruvian Expedition of 1912 under the Auspices of Yale University and the National Geographic Society.

The bottom of Cuzco Valley ranges from 10,000 to 11,000 feet above the sea. The higher peaks of its bordering ranges reach heights of from 14,000 to nearly 16,000 feet. Between 13,000 and 13,500 feet above the sea, there is a well-defined plateau surface, called by Gregory the "Inca peneplain." It is characterized by much gentler slopes than those of the deep canyons which have been incised into it by the present streams. It is underlain for the most part by complexly folded and faulted sedimentary rocks. Quaternary glaciation molded all of this region above 13,500 feet, and occasional moraines descend to 12,500 feet.

The Cuzco Basin, occupying the upper end of the valley, is about ten miles long by three miles wide. It is believed to owe its origin to faulting. It is floored with lacustrine sediments, probably of pre-glacial age, which are overlapped by large alluvial fans, now being dissected. At the head of the valley is a plateau surface sloping from 11,500 feet up to 13,000 feet above sea-level, underlain by Cretaceous limestones carrying marine fossils—the only marine sediments known in this region. The great bulk of the mountain masses surrounding the valley is made up of clastic sedimentary rocks: brown sandstones, chocolate shales, and conglomerates. These are divided by Gregory into three formations, one of which is composed chiefly of pyroclastic material. They are tentatively assigned to the Permian and Jura-Trias. There

are also mapped several bodies of intrusive diorite and syenite, and small areas of andesitic and basaltic lavas, all doubtfully assigned to the Tertiary.

C. W. T.

Boone County. By C. E. KREBS and D. D. TEETS, JR. West Virginia Geol. Survey, 1915. Pp. 648, pls. 52, figs. 3, maps 2.

County reports now published cover the greater part of the northern and western sections of the state. In these reports are chapters on physiography and mineral resources, but those treating of the stratigraphy of the area are of more general interest.

In Boone County the outcropping rocks range in age from the middle of the Conemaugh to near the base of the Kanawha series. The Kanawha has a remarkable development. It has been differentiated into 29 formations totaling 1,844 feet in thickness. About 30 coal beds from 1 to 15 feet thick are intercalated in the series. Scores of partial sections are given.

There is a preliminary report on the paleontology of the county, and an excellent geologic map accompanies the report in a separate cover.

W. B. W.

Guidebook of the Western United States. Part B, The Overland Route. By W. T. LEE, R. W. STONE, H. S. GALE, and OTHERS. U.S. Geol. Survey, Bull. 612, 1915. Pp. 244, pls. 50, figs. 20, maps 25.

This series of guidebooks is without question the best ever published and should find a wide use among the traveling public of the United States. This volume serves at once to direct the attention of the traveler to the things most worth observing in the land through which he passes, and to render more interesting every stage of the journey. Even the best-informed person, who has been over the route many times, cannot fail to profit by the use of it, and those planning a trip for the first time will find in it by far the most complete, reliable, and attractively written guide available. A wealth of historical, geographical, and geological information is woven together into an interesting and comprehensive whole, written in narrative style. The industries and agricultural and mineral resources of the regions passed through are discussed, and a few

appropriate statistics are given. Withal, the book is not too long to be easily read in the course of the journey.

Although technical terms are consistently avoided, with the exception of a few essential ones which are explained in a brief glossary, a large amount of geological information of general interest is included. The numerous photographs are exceptionally well chosen, and well adapted to awaken interest in geology. There are 25 admirable maps on a scale of 1:500,000, showing topographic, geologic, and cultural features, and mounted in a manner convenient for the reader.

This bulletin covers the route followed by the Union Pacific from Omaha to Ogden, that of the Southern Pacific from Ogden to San Francisco, and that of the Oregon Short Line from Ogden to Yellowstone National Park. It is obtainable from the Superintendent of Documents, Washington, D.C., for fifty cents, postage free.

C. W. T.

Gold on the North Saskatchewan River. By J. B. TYRRELL. Canadian Mining Inst., Toronto, 1915, pp. 68–81.

Summarizes the general geology of the region, and describes the occurrence of gold in the gravels of the stream. The gold is said to be most abundant from Goose Encampment to Beaver Lake Creek, a distance of 130 miles. Some gold has been recovered from gravel taken out for use on the streets of Edmonton.

A. D. B.

Die mikroscopische Untersuchung der Erzlagerstätten. By Georg BERG. Berlin, 1915. Pp. 198, figs. 88.

A book for use in the laboratory. The work is divided into four parts, as follows: (I) optical and microchemical methods, covering opaque and transparent minerals, reactions for the identification of compounds and elements, chemically and by means of *anlauf farben;* an appendix deals with manipulation, separation, and preparation of material, etc.; (II) microscopic characters of the more important ore and gangue minerals; in this section the minerals discussed are grouped according to crystal system; in addition to their appearance under the microscope, the more important physical characters are given. Associated minerals are usually mentioned; (III) the microscopic structure on the important types of ore deposits; a large number of figures illustrate typical sections of the various kinds of deposits; the grouping is

genetic and mineralogic; (IV) petrography of the thermally and pneumatolytically altered rocks.

The work should be of great value, as it is the most complete that has come to the reviewer's hands, and the field is one of great and growing importance. As a pioneer work it will doubtless need additions in the near future, but for the present it fills a long-felt want.

A. D. B.

Mineral Resources of New Mexico. By FAYETTE A. JONES. Bull. 1, State School of Mines Mineral Resources Survey of New Mexico. Socorro, 1915. Pp. 77, map 1.

A catalogue of the various mineral products that the state is thought to be capable of producing. The entire lack of statistics of production detracts from the value of the book, and the potential possibilities of the state in the matter of resources not now being exploited is left largely to the optimism of the reader.

A. D. B.

A Gold-Platinum-Palladium Lode in Southern Nevada. By ADOLPH KNOPF. U.S. Geol. Survey, Bull. 260-A. Washington, 1915. Pp. 18, pl. 1.

Describes briefly the occurrence of a gold-platinum-palladium vein in dolomite in the Boss mine in the southern point of Nevada. The claim was first worked for copper, as the gold, occurring in black particles, was not readily recognizable as such. The veins are strongly oxidized and present development does not reveal conclusive evidence as to the origin or the original mineralogical character of the vein. The deposit apparently adds a new type to the list of American ore deposits. Values up to Pt. 99 oz., Au. 111 oz., and Pd. 16 oz. are reported.

A. D. B.

Guidebook of the Western United States. Part C, The Santa Fe Route. By N. H. DARTON, and OTHERS. U.S. Geol. Survey, Bull. 613, 1915. Pp. 194, pls. 42, figs. 40, maps 24.

This bulletin is in all respects a mate to the preceding, organized in the same effective way. The many simple structure sections which accompany this work, and which give even the most casual reader a fair conception of the geologic structure along the route, are especially to be commended.

It is to be hoped that the demand for these guidebooks will be sufficient to warrant their revision and republication from time to time, so that they may be kept thoroughly up to date. It is suggested that in future editions a set of small maps of the individual states be added, to give the reader a more complete geographic background for the detailed route maps than is afforded by the single physical map of the United States which is included in each volume.

Bulletin 613 covers the route of the Atchison, Topeka & Santa Fe Railway from Kansas City, Missouri, to Los Angeles, California, with a side trip to the Grand Canyon of the Colorado. It is obtainable from the Superintendent of Documents, Washington, D.C., for fifty cents, postage free.

C. W. T.

"Diamond Fields of German South-West Africa." By C. W. BOISE. *The Mining Magazine* (London), June, 1915, pp. 1–14, figs. 8.

These fields, which produced nearly $15,000,000 worth of diamonds in the year 1913, constitute a narrow strip along the coast in the southwestern part of the colony. The productive area is about 75 miles long, nowhere extending more than 12 miles inland. It is a barren desert, swept by the south trade winds, and has an annual rainfall not exceeding 2 inches. The coastal tract is characterized by low north-south ridges separated by stretches of sand and fine gravel, in which the diamonds are found. The productive stratum is at the surface, and averages not more than six inches in depth. The deposits are in effect *eolian placers*, in which the diamonds have been concentrated by the sifting action of the wind, which winnows out the finer and lighter material. The richest concentrations are often found in streaks parallel to the direction of the prevailing wind. The average size of the diamonds found increases toward the southern part of the field, but their original source is unknown.

C. W. T.

Coal Fields of Pierce County. By JOSEPH DANIELS. Washington Geol. Survey, Bull. 10, 1914. Pp. 146, pls. 30, figs. 23.

The coals of this county are all in the Puget formation of Eocene age. This formation consists of sandstones, shales, and coals and attains a remarkable thickness, estimated at 15,000 feet. The beds have been

sharply folded and faulted. A heavy mantle of glacial drift covers most of the county, and details of structure are learned only from mine workings. No estimate is made of the amount of coal available.

W. B. W.

Geology and Water Resources of Tularosa Basin, New Mexico. By O. E. MEINZER and R. F. HARE. U.S. Geol. Survey, Water Supply Paper 343, 1915, pp. 317, pls. 19, figs. 51.

The Tularosa Basin is shown to be a down-faulted block between highlands of Cretaceous, older Mesozoic (?), and Carboniferous sedimentary rocks lying upon granite. The Pennsylvanian Manzano group of Red Beds here has a thickness of about 2,500 feet, and contains much gypsum. Tertiary intrusives of several types cut the older rocks. The valley bottom is covered with Quaternary deposits, comprising water-laid gravels and finer sediments several hundred feet thick, together with modern dune sands and saline deposits. There are two recent lava flows, with well-preserved cinder cones and craters.

An unusual feature of this valley is an area of 270 square miles of dunes of gypsum sand, still in motion. The gypsum is derived from deposits on the floor of a large alkali flat to windward (west) of the dune area. The gypsum of the playa in turn was derived from the bedded gypsum in the Manzano group, the solution of which has given rise to numerous sink-holes, locally so abundant as to have produced karst topography.

C. W. T.

Limestone Road Materials of Wisconsin. By W. O. HOTCHKISS and EDWARD STEIDTMAN. Wisconsin Geol. Survey, Bull. 34, 1914. Pp. 136, pls. 41, figs. 2.

The importance of thorough investigation of road-building materials is shown by the fact that this state appropriated approximately $1,250,000 for highway purposes in 1914. This report treats of limestone materials only. Part I describes various standard tests on road materials and emphasizes the importance of thorough testing. The chief limestone horizons are discussed briefly. Part II takes up by counties the limestone areas of the state. There is a brief description of limestone resources, with results of samples tested, and 40 areal geology maps of different counties. Wisconsin is said to be more abundantly supplied with road materials than any of the neighboring states.

W. B. W.

Logan and Mingo Counties. By R. V. HENNEN and D. B. REGER. West Virginia Geol. Survey, 1914. Pp. 776, pls. 15, figs. 23, maps 2.

The 1914 contribution to the excellent series of county reports of this state includes two counties on the southwestern border. The general treatment is similar to that of earlier reports.

The strata exposed range from middle Pottsville to the lower members of the Conemaugh series. A large number of detailed sections of these series are given. A table of 150 coal analyses, both proximate and ultimate, is given, and under separate cover is a map showing areal and economic geology and structure geology.

W. B. W.

Biennial Report of Vermont State Geologist. By G. H. PERKINS and OTHERS. 1913–14. Pp. 448, pls. 78, figs. 41.

The greater part of this report treats of the marble industry of the state. It contains reprints of *Bulletins 521* and *589* of the United States Geological Survey which deal with commercial marbles of this area.

Separate articles by various writers give brief résumés of the geology and mineralogy in the vicinity of Hardwick, Woodbury, and Bennington. The talc deposits of the state are described by E. C. Jacobs. He believes that these deposits have resulted from the metamorphism of basic intrusions into sedimentary country schists.

W. B. W.

Biennial Report of Missouri Bureau of Geology and Mines. By H. A. BUEHLER. 1913–14. Pp. 62.

This is chiefly an administrative report of work completed by the survey staff during this biennial period. Statistics on mineral production in the state during 1913 and 1914 also are given.

W. B. W.

Devonian of Southwestern Ontario. By C. R. STAUFFER. Geol. Survey of Canada, Geol. Series, No. 63. Pp. 341, pls. 20, map 1.

Devonian beds outcrop over the entire area of the Ontario province that projects southwest between Lakes Huron and Erie. Probably the entire system is present although the correlations of the upper and

lower members are still tentative. The beds rest unconformably on Silurian rocks ranging in age from Salina to Cobleskill or younger. The revised classification follows:

- Devonian
  - Upper
    - Port Lambton (probably Portage or Chemung)
    - Huron shale (probably Genesee)
  - Middle
    - Hamilton
      - Ipperwash limestone
      - Petrolia shale
      - Widder beds
      - Olentangy shale
    - Delaware limestone
    - Onondaga limestone
      - Onondaga limestone
      - Springvale sandstone (local facies)
  - Lower
    - Oriskany sandstone
    - Helderbergian (wanting or possibly represented in the Detroit River series)

From 2 to 10 sections are given in each of the 12 counties included in the area. The paleontology has been worked out with great care and each section is accompanied by its fauna classified by horizons. Of the species given, 350 are listed from the Hamilton beds alone and 347 from the Onondaga. Largely on faunal evidence the Springvale sandstone is considered a local facies of the Onondaga instead of belonging to the Oriskany.

There is a chapter that summarizes present knowledge of the development and migrations of the Devonian faunas in this region and a chapter of bibliography on the Devonian of the eastern continental area.

W. B. W.

Central Connecticut in the Geologic Past. By JOSEPH BARRELL. Connecticut Geol. and Nat. Hist. Survey, Bull. 23. Pp. 44, figs. 9.

This bulletin is a study of the extent to which ancient geologic structure and physiographic features may be reconstructed from data now available. Technicality has been avoided in an attempt to make the report available for general reading. To further this plan the historical geology is taken up in reverse of the usual order.

A number of wholly new structure sections are of chief interest. These sections reproduce the structure for each geologic period since late Paleozoic times. There is a departure from conventional structure sections in that clouds and the landscape of the background are added. These features may be of aid to readers untrained in geology.

Many of the generalizations on the great events of geologic history apply to a much larger area than that named in the title of the report.

W. B. W.

Peat Resources of Wisconsin. By F. W. HUELS. Wisconsin Geol. Survey, Bull. 45, 1916. Pp. 274, figs. 20, pls. 22.

As neither oil, natural gas, nor coal is found in this state, special interest attaches to its peat deposits, and has resulted in their systematic examination. Part I contains a general discussion of the origin of peat, its preparation and uses. Part II gives a description of the state's peat deposits. These are limited to the drift-covered area. The quantity of peat land is placed between two and three million acres and the amount of peat between two and three billion tons. Analyses show that for the most part the peat compares favorably in quality with peats now being used extensively in Europe.

A number of companies have engaged in peat production but all have suspended operations. It seems probable that the greater part of the peat lands will be drained and reclaimed for agricultural purposes.

W. B. W.

Soils of Mississippi. By E. N. LOWE. Mississippi Geol. Survey. Pp. 220, figs. 22.

This is a preliminary dicussion of the subject and is to be followed later by a complete report. The state is divided into 9 soil areas that correspond roughly to physiographic provinces. The soil of chief geologic interest is found in a belt of loess, that extends the length of the state, and borders the Mississippi River flood plain.

An appendix to the report contains a number of soil analyses.

W. B. W.

Hudson Bay Basins and Upper Mississippi River. U.S. Geol. Survey, Water-Supply Paper, 355, 1915.

This volume is one of a series of twelve reports of measurements of stream flow in the United States during 1913. The data cover the flow of the larger streams in Minnesota draining into Hudson Bay and those of Minnesota and Wisconsin that are tributary to the Mississippi.

W. B. W.